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A SCIENTIFIC SEARCH FOR THE SECRET OF STRADIVARIUS.*

BY

F. A. SAUNDERS, Ph.D.,

Professor of Physics, Harvard University.

It appears to be an almost universal belief that violins reached perfection in the hands of a few makers in Cremona, and that the secret of their construction has been irrecoverably lost. In many other fields of human activity the work of modern times is accepted as superior to that of two or three centuries ago. This contradiction is a challenge to any inquisitive investigator, especially as the technique of investigation has developed to an extraordinary degree in recent years, so that the validity of this belief can now be tested in a way that was impossible even so recently as a few years ago. The problem of an experimental investigation of violins has been attacked many times before and some interesting results have been obtained, but some five years ago it was decided to attack it again by the most modern methods, under the instigation and with the generous support of Mr. H. S. Shaw of Boston, who is interested in the question both from the musical and from the scientific side.

The aim of this work has been to find out how violins of unquestioned reputation act when played in the usual manner, that is, to investigate the sound waves which come from them.

* Presented at the Annual Meeting held Wednesday, January 18, 1939.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

and to try to deduce from these how the violins vibrate. If it should be found that there are certain peculiarities in the vibrations of the best violins, it ought to be possible to trace the cause of these to some element of their construction, the properties of the wood, the varnish, or some other of the many features which they exhibit. It is hoped that from this work may come some contribution to the problem of supplying the world with substitutes for the greatest instruments when these wear out. This sad event is expected to occur within a couple of centuries.

One may reasonably take the price of a violin as a rough indication of the agreement of artists as to its value; at least one may be sure that a violin costing $50,000 is certainly better in some respects than one which costs only $50. It was decided early in the investigation that Stradivarius violins of unquestioned genuineness would yield valuable results, which would be accepted on account of the reputation of this maker. The best instruments of Joseph Guarnerius (del Gesu) are certainly worth testing also, and perhaps those of other makers. To avoid complications due to the effect of the shape attention has been concentrated almost entirely on violins of the flat Stradivarius model, or others deviating very little from it. Many illustrious violins have now been studied, and more will be done later. Some dozen of the very best old instruments, and thirty odd good and bad modern violins have been examined in the attempt to find differences in the mechanical behavior of the old and new ones.

It was evident before beginning this work that all the old violins have been altered since they were first given to the world. Many have suffered accidents, or have cracked from atmospheric changes. The rise in musical pitch since 1700 has been appreciable, and the strength of the old instruments has not been sufficient to withstand the strain of the increased tension in the strings necessary to meet this rise of pitch. The bass bar, which is a strengthening member glued to the under side of the top plate (the belly) of the violin, has had to be lengthened and thickened on this account. Another reason for this change has perhaps been a desire to produce a louder tone in order to fill the concert halls of the modern era. Such a structural alteration inevitably changes the behavior of the

violin from a mechanical standpoint, much as soldering a mass of metal to the side of a bell would modify the vibrations of the bell. It is a tribute to the skill of modern violin makers to say that this change has not ruined the instruments. In fact it may be that it has actually improved them. The early part of our work showed great differences in the action of Stradivarius violins, and the suspicion that repair operations may have been responsible for these led us to test as many as possible of the most famous violins available. These are all in the hands of collectors and great artists, and we owe many thanks to the individuals who have so kindly given us opportunities to investigate their instruments. The difficulty of securing these opportunities is obvious, and the results are still incomplete.

Before attempting to give any results we must consider what is worth measuring, and how it can be measured. The most important single item about a violin should not be its appearance, beautiful as that may be, but its tone quality. What is meant by this expression? There has been much discussion recently about piano touch in which most of the differences of opinion have arisen on account of a lack of precise definition of the terms used. We shall therefore try to avoid such quarrels by admitting that many people include in the term tone quality certain features which are properly to be ascribed not to the instrument itself but to the artist using it, such as the shading, the phrasing, the vibrato, etc. To a physicist any musical tone consists actually of a mixture of tones the lowest of which is the fundamental or first partial tone, which gives the pitch, and a series of overtones, harmonics or upper partial tones. If the upper partial tones are absent, as is nearly the case in the tone of a flute or French horn when softly blown, the tone is said to be a pure tone; the musician describes this tone by a series of somewhat vague adjectives: soft, sweet, hollow, dull, round, etc. If the upper partials are strong and the fundamental weak we get an impression of shrillness, which may be called brilliancy, soprano quality, brightness, "bite," etc. A shrill violin usually "carries" well, that is, it is heard over an accompaniment in the same way that a shrill voice can be followed in a conversation on a noisy car. This is due to the very high

sensitiveness of the ear for the high partial tones which are responsible for the shrill quality. Many violinists prefer this quality, especially for orchestral playing. An oboe or a piccolo can be heard without difficulty in an orchestra for the same reason. From a study of such examples physicists have concluded that the quality of a tone depends on the presence and strength of the upper partial tones which constitute a part of every complex sound, and which permit us to recognize the instrument from which it comes. We shall use the term quality always in this limited sense.

It is generally believed that the quality of the tone of a violin is a certain definite thing, even in this restricted sense, and that the artist may alter this quality at will. If so, the study of violins would be inextricably mixed up with the study of artists. We have been led to the opinion first that the quality of a violin is not definite but varies from note to note, and that a technique can be used which eliminates the contribution of the artist entirely. We demand, or rather the requirements of our measuring instruments demand, that a tone which is to be studied shall be produced without change of loudness for a period of five seconds, no more, no less. This takes one bow length. If one must hold the loudness steady for exactly this length of time, and use a whole bow length to do it, one cannot make much change in quality in the process. An earlier part of our studies showed that the quality changes very little with change of bow pressure alone, but it alters somewhat with bow speed and bow distance from the bridge. If both speed and position on the string are kept reasonably constant, repeated observations show that no considerable change in tone quality can occur. Of course vibrato is also excluded, as that would involve undesirable changes, varying with the player. Results so far obtained show that with these restrictions the tone obtained is the same no matter who does the playing, provided he can draw a smooth even bow. Hence we feel that we have eliminated the artist, and have a means of testing the violin as though it were speaking by itself. Treating all violins by an identical procedure we can thus make just and adequate comparisons.

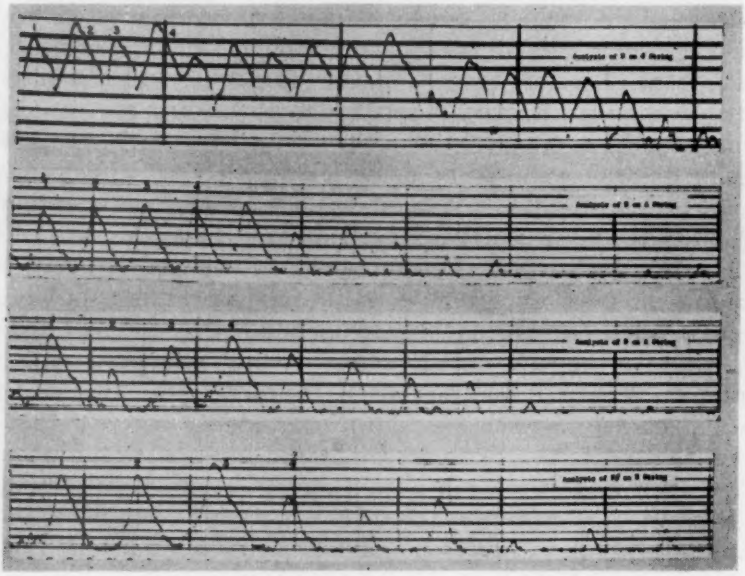
The measurement of the quality of a tone involves finding a means of sorting out the upper partial tones from the funda-

mental and from one another, and measuring the loudness of each by itself. A harmonic analyzer for this purpose was built in the Physics Research Laboratory at Harvard through the coöperative effort of many individuals, but the credit should go largely to Dr. H. H. Hall, who has published a technical description.[1] The tone is received by a high-quality microphone and the resulting electrical vibrations are so treated by the analyzer that a photographic strip emerges from the instrument, which after development shows the intensity (in decibels) of each component of the tone, as well as the frequency in cycles per second, upon which the pitch depends. For the purpose of this elementary discussion we may treat the intensity observations as yielding the approximate loudness of each component, although strictly speaking some allowance should be made for the varying sensitiveness of the ear with pitch. We find on these strips sometimes more than thirty upper partials recorded, with the loudness of each definitely measured. The most skillful ear can scarcely be aware of more than ten of these and no ear is capable of *measuring* the strength of any of them. If they could be heard separately the ear might estimate their relative strength, though very roughly, but when they all sound together it is incapable of yielding even approximate estimates. Hence we feel that in this analyzer we have a most powerful helper, and that with it we can obtain results incomparably better than any that can be reached by ear alone. The usual procedure with one violin is to make analyses of each tone twice (to avoid accidental variations in bowing) and to study an octave, thirteen tones a semi-tone apart, on each of the four strings, with an additional octave on the high E string. This means playing sixty-four notes, each of them twice. Of these notes some are duplicates, but played on different strings. There are actually forty-six different notes played, when duplicates are not counted. In another investigation of this sort which is now being carried out by H. Meinel in Germany, eight different notes are played in each whole tone, a procedure which is desirable but so time-consuming as to be prohibitive in the sort of general survey that we have undertaken. Our method ought to lead to valuable conclusions without further

[1] H. H. Hall, *Journal of the Acoustical Society of America*, **7**, 102, 1935.

refinement. The appearance of the individual analyses is shown in Fig. 1, a record of parts of four analyses of tones produced by Heifetz on his celebrated Guarnerius. The different arrangement of loudnesses among the partial tones in the four notes is well shown. The upper record is of B on the G string, the next B on the A string, the third D on the A string, and the lowest F♯ on the E string.

FIG. 1.

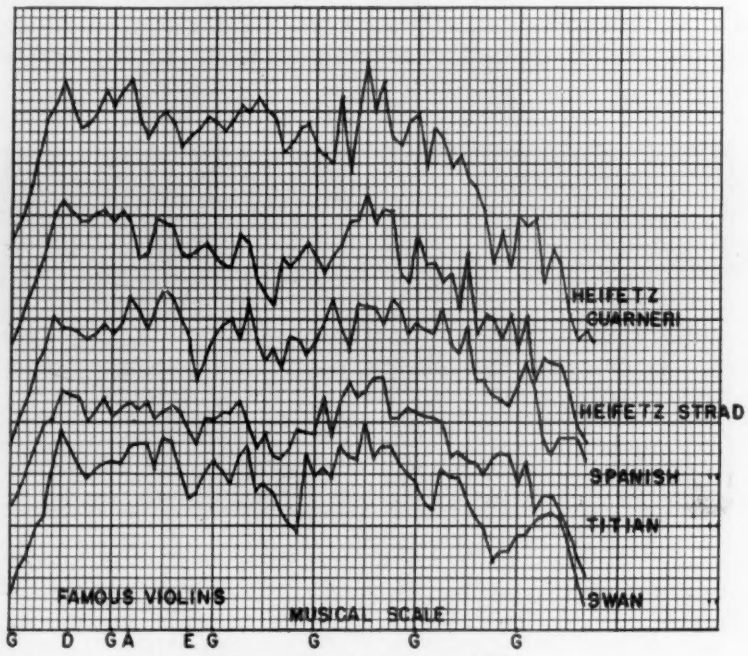


Analyses of four tones produced by Heifetz on his Guarnerius. The heavy vertical lines give frequencies in thousands; the horizontal lines give (approximately) loudness. The top record yields for successive partial tones the loudness values 39, 44, 40, 45, 33, 39, 35, 39, 39, 42, 22, 34, etc.

The loudnesses of the partial tones are read off the photographs in decibels (db) and tabulated. A single set involves over 1500 observations, which are so numerous that they are hard to interpret. At present we do not use all of them, but for reasons that we need not go into attention is confined to the first four in each analysis. These are the fundamental, the second partial an octave higher, the third partial a fifth higher still, and the fourth partial which is the double octave. Some of the partials lying still higher would not fit exactly on the musical scale, which makes them awkward to use. A

diagram is then made using as the base line the musical scale, like the piano keyboard, though restricted at the lower end to the lowest notes of the violin. We plot vertically above each note the loudness corresponding to that note, whether it occurs as fundamental or upper partial. Then we run a curve through the average of all the points thus placed. Thus we derive a curve which can best be described as the response

FIG. 2.



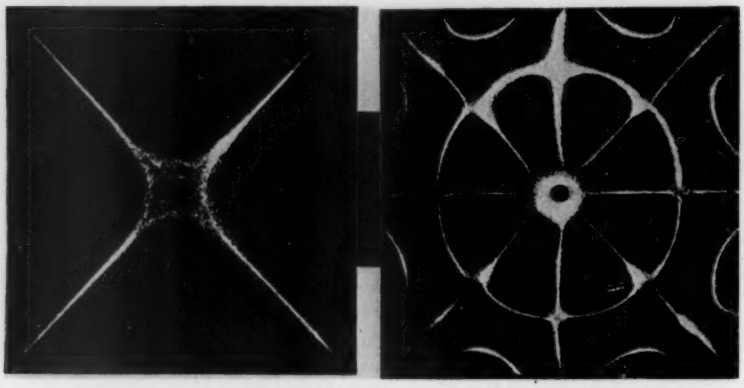
Response curves of five famous violins.

curve of the violin, because it gives the response of the instrument at each note. It yields the loudness of the fundamental tone at each note, but the curve extends two octaves above the highest note played, since the fourth partial is one of those plotted.

The response curve contains in compact form a working summary of all the photographic records of the analyses. The latter by themselves show an embarrassing mass of details from which we can conclude only that each tone of any

one violin has a quality which is different from that of every other tone given by that instrument. This is bad enough, because it means that there is *no one quality which is characteristic of any violin*, or of those of any particular make. The response curves, of which several are shown in Fig. 2, yield the reason for these differences. Each shows certain peaks and hollows. At each peak the violin responds more than usual, and gives a loud fundamental tone when the note is played at which the peak occurs. This is due to a natural resonance, or sympathetic vibration, of some part of the violin (usually of the top plate) at this particular frequency. An analogy can

FIG. 3.



Two sand patterns obtained by bowing a Chladni plate. The simple one corresponds to a low note, the complicated one to a high note.

be drawn from the behavior of a flat plate of metal, often shown in physics classes as a Chladni plate. Fig. 3 shows a brass plate, fastened at its central point to a firm support. Some sand has been sprinkled on it and one or two fingers have been pressed firmly against it at certain places in order to keep these at rest. Some other point on the edge has then been bowed with a resined bow so as to make the plate vibrate. The result is that the plate breaks up into segments, divided by nodal lines which are at rest, the regions on opposite sides of each line vibrating in opposite phases. The vibrations toss the sand particles about so that they settle on the nodal lines and thus disclose the subdivision of the plate. Dozens of

different patterns may readily be obtained with a square plate, and to each pattern corresponds a note of a certain pitch, which is a natural vibration of the plate. Such patterns resemble those into which the top of the violin divides when a tone is produced which resonates with one of the natural vibrations of the plate. Thus a single plate may resonate to as many tones as the number of possible patterns into which it can break. When the areas in the patterns are small and the pattern complicated the pitch of the resonating tone is high. As so many patterns may be obtained with a square metal plate, it is no surprise to find many resonant tones coming from the top of a violin. The fact that this is a less simple structure would lead us to expect an even more complicated response. Its vibration will be affected by the sound-post just behind the right foot of the bridge, which connects the top plate with the back. Then the plates are bound all around their edges by being glued to the sides of the violin, the bass bar already mentioned introduces a complicating lack of symmetry, and finally there are the two f-holes cut in peculiar fashion which further aid in destroying the simplicity of the structure and therefore of its possible vibrations. All but one of the main peaks on the response curve may be explained as due to resonance in the *body* of the violin. That one is the one of lowest pitch, usually near the open D, which is due to sympathetic vibration on the part of the *air* included inside the violin. At this pitch the greater part of the sound is produced by the air rushing in and out of the f-holes, as happens in a flute, for instance. In consequence that particular tone is noticeably different in quality from the others near it.

The response curves obtained with different violins differ from one another because the violins differ a little in dimensions, and the wood of which they are made is seldom alike in grain, density, elasticity, etc. These variations produce differences in the strength of the upper partials of any tone, and thus in the tone quality all over the range of the violin. One may read off the strength of the upper partials of any tone from the curve, and then do the same for a tone a semitone higher. Certain partials will be seen to be considerably different in strength, even for this small shift. The ear might

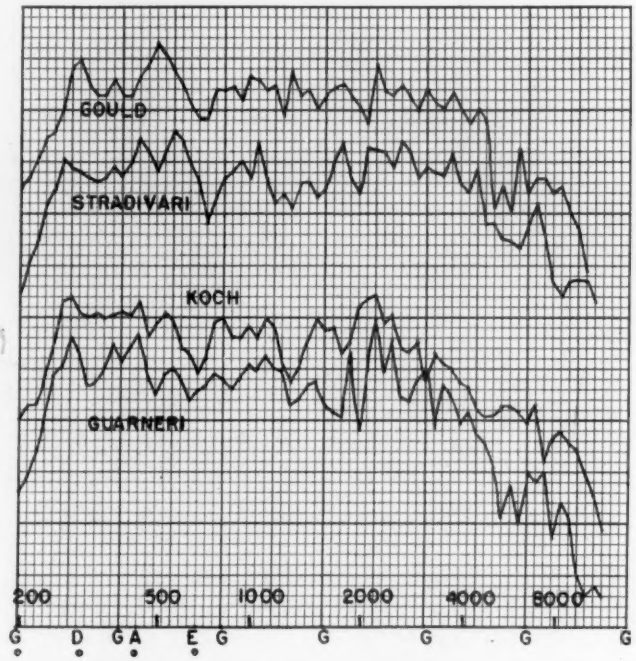
not notice the difference, but the curve shows it, and it is real. In Fig. 2 the response curves of five famous violins are plotted one over another so as to facilitate comparisons. The similar peak common to all near the open D is obvious. Its position is fixed by the internal volume and the area of the two f-holes combined. It lies in a region in which the response of the violin would otherwise be weak, and its beneficial strengthening effect is felt over three semitones each way. The other peaks represent natural vibrations of the body. We know this because the addition of a load (a mute) to the bridge lowers the pitch of these peaks in accordance with the general rule that heavy bodies vibrate slowly. Vibrations of the air inside the body are unaffected by loads on the bridge, so that these do not shift the peak near the open D. Each body peak corresponds to a different mode of subdivision of the vibrating plates. Probably the top plate is more important than the back, especially for the higher tones given by the violin.

What are the features of the response curves of the best instruments? The most striking and embarrassing feature is that they do not agree, but differ considerably from one another, as Fig. 2 shows. In some the body peaks are very pronounced, with deep hollows or regions of poor response between; in others the response is more uniform. Many violins have a hollow in the lower octave on the E string, often near D, but sometimes as far down as the open string. The effect of these hollows in general is to reduce the volume of tone at these pitches, and to change its quality. A reduction in volume is bad, but it may happen that a weakness in the fundamental tone is compensated by unusual strength in one of the upper partials. Whether marked differences in tone quality in nearby notes are to be regarded as bad is not quite certain. Many excellent violins have this peculiarity, and their owners are not always aware of it. Variety may even be pleasing. One should note also that peaks and hollows usually become narrower as one goes up the scale, with the consequence that the free use of the vibrato, now so universal in solo playing, tends to blur out these unevennesses. It is in this sense, and probably in this sense only, that the vibrato affects the tone. If a note is being played whose fundamental tone happens to lie on the tip of one of these sharp peaks the

slight change of pitch due to the movement of the finger in the vibrato tends to reduce the otherwise too great loudness of this component of the tone. This helps to remove the objectionable results due to the presence of strong peaks in the high-pitch range.

From a study of many response curves it seems most probable that the best violins are those which have a fairly

FIG. 4.

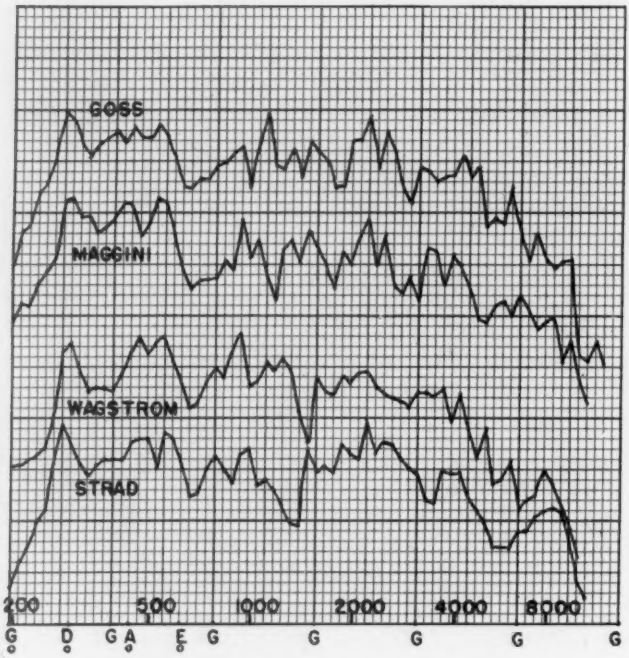


Similar response curves in pairs, one an old violin, the other a new.

uniform response level over most of the range, with a little excess in the region near the top of the E string (2,000 to 3,000 cycles per second), and a rather sharp dropping off to nothing in the highest pitches (from 5,000 to 10,000). This implies a tone rich in upper partials in the lower notes and with comparatively few in the highest. Curves fitting this somewhat vague description are obtained from new instruments as well as old, and the similarity is sometimes very striking. Fig. 4

shows that the curve for the "Spanish" Strad (1724) is closely followed in general, and even in some details, by the curve of a violin made by J. A. Gould of Boston (1889). The general resemblance between the curves of the Heifetz Guarnerius (1742) and the Koch Guarnerius-copy (1930) is well shown in this figure, though one can see that the real Guarnerius has high peaks near 2,000 cycles which may give it superior

FIG. 5.



More response curves of paired old and new violins.

"carrying power," as explained above. These four violins have fairly even response curves. The Swan Strad (1737) used by Baloković (see Fig. 5) shows a rather deep hollow at the E octave on the E string, and its curve resembles in general that of a violin made by Wagstrom (Youngstown, Ohio) in 1938. This figure shows also the curve for a Maggini violin owned by Prof. F. G. Keyes of Cambridge, Mass., against one made by W. S. Goss in Boston in 1912. All of these curves

could be somewhat altered by changes in the adjustments, particularly in the higher pitches. From a study of such similar pairs of violins one concludes that no one form of response curve is definitely required as a mark of excellence, and that age is not necessary to produce a given form. In fact, if the value of a violin is based on its tone quality as here measured alone, we must conclude from these examples and many others that modern violins can be built which produce the same sorts of response curves, and therefore have on the average the same tone quality, as the best old violins.

This statement is very repugnant to most musical people and especially to violinists, who know that there is an undefined something about an old violin which is immediately felt by the player, even if it is not recognized by the listener also. The objectionable statement says merely that if we define and measure the tone quality as above the superiority of the old violins lies not in their tone quality but somewhere else. Our work has, we think, recently given a clue to the real reason for the superiority of old instruments. It lies in the amount of work that has to be done on them to make them "speak" properly. A motor-operated machine has been made which bows a violin string by means of elastic celluloid disks whose outer edges rub against the string much as a bow does. The tone produced is closely similar to that of a "real" bow. The disks can be rotated at various speeds, and the arm that carries and rotates them is pivoted like the arm of a balance, so that the pressure of the bow on the string can be measured and kept constant, as well as the distance from the bridge and the speed of the bow. With this device one finds that a very light pressure is insufficient to produce a good tone, but by adding weight to the arm one produces a proper tone at a certain weight, whose value is rather critical, and is easily measured. One can find the least power needed to make the violin produce any tone in its range. These values are high at the peaks of the response curves, and a "wolf" tone is always obtainable at each peak if the weight used is insufficient. This is true of all violins, good, bad, old, and new. The average value of the work needed for the notes in an octave on one string is thus found. These values show a slight difference in old and new

violins, the new usually being harder to play, sometimes by as much as a factor of two.

This mechanical difference produces effects of great importance to the player. When he comes to the end of a bow-length he turns and begins to put force on the string. The old violin begins to sing a small fraction of a second before the new one. In a rapid passage where the note may last only a small part of a second, the least balkiness on the part of a violin may determine whether the player fails or succeeds in producing this tone. Hence to the player when engaged in violin gymnastics, a common occupation of the best solo violinists, the ease of response may be more important than anything else, even the tone quality. To him the expensive violin is worth what it costs. To the listener who is unaware of the difficulties it means less. A violinist acting as a listener may, if he is keen enough, hear the easy start of each tone, and appreciate the help which the old violin gives to the player. To such a rare listener the violin may be worth a high price, but the average listener, whether musical or not, appears to be unable to say whether he is hearing a masterpiece of Cremona or a good modern violin.

To illustrate this point The Franklin Institute audience listening to this lecture was asked to coöperate in an experiment. Three violins were most admirably played in rapid succession by Mr. Oscar Shumsky. They were known to the audience only as A, B, and C, and they were played behind a light screen. Nothing was said about them except that one was a beautiful Stradivarius (the "Rossignol" of 1717, graciously lent for the occasion by Mme Luboshutz). Each listener was given a card on which to record his vote, and was asked to state which violin was the Stradivarius. The other two instruments were very good, each of recent make, one by Moennig of Philadelphia, the other by Koch in Dresden, Germany. Almost exactly one third of the audience who voted (about 170 votes were handed in) got the Stradivarius correctly, and one third is the number obtained if the choice were made by pure chance. Those of the audience who were musical did no better than the rest. A considerable proportion of the audience admitted that they were uncertain in their judgments. Some fifty said they were not uncertain,

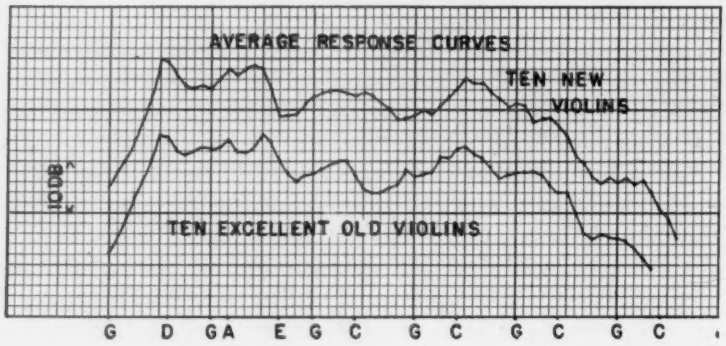
and of these nearly half got it right, while slightly more than half preferred one or the other of the new violins. It was obvious that a few of the listeners, perhaps not more than a dozen, could recognize the tone of a Stradivarius at once, by ear alone, and without hesitation. Some persons who are justly regarded as experts did not vote correctly. The wood of the Koch violins gets special treatment which tends toward softening the tone (i.e. weakening the vibrations above 5,000 cycles per second). Over half of the audience liked the tone of the Koch instrument, and thought it was old Italian. Violins are often preferred for chamber music if they do not possess extraordinary strength in their highest vibrations, and though such instruments may lack a certain amount of carrying power this did not show in the test as the violins were unaccompanied. The carrying power of the Moennig violin was greater, as it was a brilliant concert instrument; nearly a quarter of the audience judged it to be the Stradivarius. These facts illustrate the well known fact that tastes differ even among violins.

When we listen to a string orchestra, with many violins playing the same note at the same time, we are aware of some difference of tone quality when a single violin is given a solo part, as in a concerto. The reason for this is plain to see. The response curve of a group of violins can be found approximately by averaging the response curves of the instruments measured separately. Since most of the peaks and hollows in the curves come at different pitches for each instrument, the process of averaging smooths out the curve so that it no longer resembles any real violin taken singly, but begins to approach the curve that is given by a radio loud-speaker of the highest quality. Fig. 6 shows how very similar the response of the average of ten old and famous violins is to that of ten well-made modern ones. One would not have to pick and choose much in the selection of the ten violins to make these two curves almost exactly the same. It appears therefore that for orchestral playing the tone quality of a group of violins is likely to be the same whether the violins are old or new. A string orchestra entirely composed of Stradivarius instruments played in a concert in New York in December, 1937, and many listeners could hear nothing unusual in their combined tone.

The ease of response will still give their possessors some practical advantage, but unless the group plays together with superhuman precision throughout difficult passages this will not be apparent even to the most skilled and gifted listener. Since most orchestral players cannot afford to use very expensive violins, it is a comfort to know that we are losing practically nothing thereby.

The tone of a violin is profoundly affected by certain adjustments which are easily made. These have long been known. The position of the sound-post, and the height, weight, and form of the bridge are the most important of these. The height of the bridge determines what fraction of the

FIG. 6.

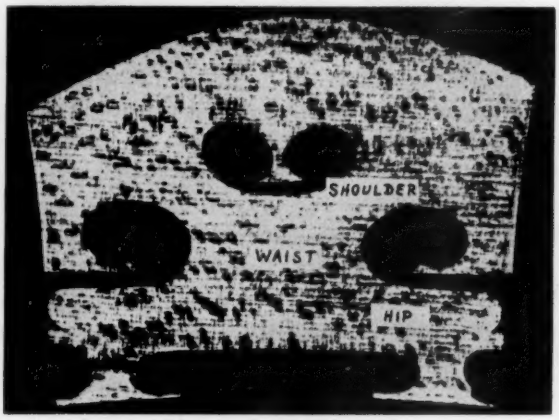


Average response curves of (below) ten old violins of high reputation, (above) ten good new violins.

tension of the strings is used to press the feet of the bridge against the top of the violin. This pressure affects the passage of the vibrations into the body, and the resulting motions there, which cause the sound which we hear. But the bridge exerts also a powerful selective effect on the vibrations furnished by the string. The latter, for instance, vibrates longitudinally (along the string) to a certain extent, producing high and very objectionable sounds. The upper part of the bridge is so cut as to yield to these without affecting the feet of the bridge, so that the latter do not transmit these unpleasant vibrations to the body, and we do not hear them. The motion of the right foot of the bridge (as seen by the player) is almost negligibly small. The left foot is the one

which transmits the useful vibrations to the body, and this rests directly over the bass bar, which serves to pass these vibrations without much loss along the length of the whole violin top. In order to reach the left foot of the bridge the vibrations started by the strings have to pass through two narrow parts of the bridge which might be called its shoulders (see Fig. 7), and through the "hip" directly to the foot. The width of the shoulders can readily be reduced by means of a file, and this little alteration has a surprisingly great effect on the loudness of the highest upper partials (above 5,000 cycles

FIG. 7.



A violin bridge.

per second). Any violin that is unpleasantly shrill can be completely cured by this simple operation. Thus one and the same violin can by simple changes be made at will into either a brilliant and slightly shrill concert instrument or a softer-toned one more suitable for chamber music. The nature of the effect of such changes is clearly revealed by a study of the corresponding response curves. Much work remains to be done on the effect of adjustments on these curves, and their interpretation. Skilled violin adjusters already know the answers from experience, though very little seems to have been published on this subject.

Another change in the bridge which is easily made and undone is to use a paper clip of the smallest of the common

sizes, forced horizontally on the bridge just under the E string. Curiously enough this does not mute the violin; the weight of the clip is too small. In fact in some cases it actually increases the loudness of all strings excepting the E string. If the latter is too shrill the paper clip takes away the unpleasant quality. The inertia of the clip appears, small as it is (0.3 gram), to be sufficient to diminish the intensity of the highest string vibrations which are transmitted to the body, and the effect is restricted chiefly to those partial tones which lie an octave or more above the usual playing range of the violin. There is a curious reluctance among violinists to try simple experiments of this sort which reminds one of a mid-westerner with his first raw oyster. One who has not tried this can have no adequate impression of the startling change which is produced. A small mean-toned scratchy violin can often be greatly improved by using a higher bridge in order to increase the volume of sound by added pressure on the body, and by one of the bridge adjustments just mentioned.

The alterations in tone quality due to adjustments raise a difficulty in appraising the musical value of any violin. It would be pleasant to assume that each instrument is always in its best condition of adjustment, or even that it was so at the time when it was being tested. Of course we cannot be sure of this. Our experiments have already yielded examples in which the depth of hollows in the response curves has been greatly reduced by changes in the adjustments. The work has not gone far enough to enable us to say that great unevennesses in response can always be reduced by adjustments, but this may turn out to be the case, and rules may be found that will help in putting a violin in its best possible condition.

It would be improper to end this discussion without some mention of the effect of varnish on the tone of a violin. This subject has been studied and written about by many people, with divergent conclusions. Very few have made any measurements of the changes produced by the addition of varnish to a violin, taking the very necessary precaution to make sure that this was the *only* change that had occurred. No one can try the effect of different sorts of varnish on the same violin for the simple reason that the first coat cannot be so completely removed as to leave the wood in its original condition.

Testing the effect of different varnishes on various violins is useless unless one studies each violin "in the white" beforehand. Even then great care must be exercised to get the same position for the sound-post, to use the same strings and other fittings, and to have the same amount of moisture in the air. An increase of humidity may add several grams of weight to the violin, and will expand the spruce top across the grain, altering its curvature and the tightness of the sound-post. The best varnish test so far made has been done by Meinel in Berlin, and this yielded the result that the varnish did not shift the pitches at which the peaks of the response curve come, but did lower the height of several of the high-pitched peaks. This means that the varnish increased the viscosity, or inner friction, of the wood so as to make it vibrate less freely in its own natural modes, thereby tending to even up the response curve somewhat. The effect was very small, however, and it is doubtful if the change could have been detected with certainty by the ear, in view of the time that must elapse between the two tests. We have carried through one similar but less precise test verifying Meinel's result; the varnish produced a negligible effect on the tone quality, and only a 2 per cent. increase in the weight.

Naturally, these two tests were probably made with different varnishes, neither of which may have been like that used by the old masters. Would the latter have given the same results? If the varnish penetrates the wood only a short distance, and forms a thin surface film, one can predict that it can produce no great change in the mechanical properties of the violin. If it penetrates to a considerable depth, however, it may alter the stiffness a little, and perhaps also the viscosity. From mechanical considerations one would infer that a considerable increase in viscosity would cut down the height of the peaks of the response curve, especially in the highest pitches. With such a varnish a violin ought to yield a weak response in the 6,000 to 10,000 frequency range, with a correspondingly pleasant tone, and would perhaps be little affected at lower frequencies. Thus it might have a good form of response curve, like that of many of the old instruments. Dr. Koch in Dresden has worked on this problem for many years and has developed an oil-varnishing

process which involves "drying" (oxidizing) the oil in ultra-violet light. This accelerates the drying, and the results seem very promising. Ordinary drying methods might yield unfavorable results with the same varnish, especially if most of the drying occurred in the dark, or in a dim light. Stradivarius probably dried his violins by weeks of exposure to open sunlight. Koch has studied the chemistry of this process, and appears to attain a similar result in a much shorter time. It is not impossible that before long we may have a method of producing the most desirable varnish effects, combined with an ease of response not yet obtained with modern violins. There seems to be no reason to doubt that we shall then be able to create violins which are in every respect equivalent to the best of the old ones. Certainly our modern craftsmen produce beautiful instruments, probably as well made as any ever were, and if antiquity has imparted to the wood any properties which new wood does not possess, the mechanical nature of these properties can be discovered and methods of treatment devised which produce these qualities in months instead of centuries. To a scientific race which has learned how to fly and to carry on conversations across the oceans such a simple problem as that of making excellent violins seems almost absurdly easy.

The writer wishes to record his indebtedness to two able assistants, Messrs. Robert B. Watson and Leo Beranek of Harvard University, for their skillful help in obtaining the recent results of this investigation.

SOLAR INFLUENCES ON THE COSMIC RAY INTENSITY AT HIGH ELEVATIONS.*

BY

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ABSTRACT.

Instrument carrying balloon flights using the radio-cosmic-ray technique have been made during the day and the night, to investigate the amount of the diurnal variation at high altitudes. It was found that the effect, if any, is smaller than the experimental error of two per cent., and is estimated to be about 1.5 per cent. of the radiation at these levels. This permits a definite upper limit to be set to any contribution of solar origin to the ionization at levels up to 0.3 meters of water equivalent below the top of the atmosphere, which could be produced by photons in that spectral region to which mass-absorption laws apply, namely X-radiation. The magnitude of the effect is in agreement with the view advanced by Vallarta, that a magnetic field on the sun would produce a small diurnal change in the intensity of the softer portion of the cosmic ray intensity.

1. INTRODUCTION.

BARTOL RESEARCH FOUNDATION
Communication No. 100.

In order to ascertain whether any component of the cosmic radiation at high elevations might be of solar origin, a series of measurements using the radio-balloon technique was carried out. A solar component might manifest itself either as a diurnal variation in the cosmic ray intensity, or as an increase in the cosmic ray intensity appearing at times when the sun's surface was in a disturbed condition, such as at the time of a solar flare. This solar component is to be distinguished from the well-known diurnal variation at sealevel, which has been studied by Hess [1] Forbush [2] and Compton [3] and others, and which is thought to be of terrestrial origin.

It is well known that solar radiation produces ionization at high levels in the atmosphere, especially above 80 kms., in

* Based on papers delivered on Dec. 28, 1938, and Apr. 27, 1939, at Washington. Abstracts, *Phys. Rev.*, **55**, 600 (1939); *Trans. Am. Geophys. Un.*, 367 (1939).

[1] V. F. Hess and H. Graziadei, *Wien Ber.*, **143**, 313 (1934).

[2] S. E. Forbush, *Terr. Mag.*, **42**, 1 (1937).

[3] A. H. Compton, R. D. Bennett and J. C. Stearns, *Phys. Rev.*, **41**, 119 (1932).

the Heaviside layer. The question arose as to whether any of this radiation could penetrate down to such levels as are accessible to sounding balloon measurements. With present technique, such balloons can ascend to 25 kilometers or more, or through about 98 per cent. of the atmosphere. At these levels the air above them is equivalent to some 0.2 meters of water. In a previous paper, Johnson and Korff [4] reported finding no increase in the ionizing radiation at a level of 0.5 meters of water at the time of a solar flare, as great as 2 per cent. of the total cosmic ray intensity at that elevation. The present experiments were designed to test whether there might be an appreciable diurnal effect at high elevations.

2. EXPERIMENTAL PROCEDURE.

A series of measurements was carried out at high elevations, the cosmic ray intensity being measured by a single Geiger counter. In these experiments four counting tubes were placed side by side and were connected in parallel, thus acting as a single counter with a sensitive area of 60 sq. cms. in the horizontal plane. The arrangement discharged at the rate of about 6000 counts per minute in the stratosphere. The pulses were scaled 50 : 1 using a circuit described by Johnson,[5] and were then transmitted by short wave radio to a receiving station on the ground. The radio technique has been previously described by various workers.[6] On the several flights the apparatus was lifted by six or eight balloons, each of which was attached to a common rigging by a simple trigger release mechanism, so that, when any balloon burst, its fabric was dropped off. By the elimination, in this manner, of the unknown residual amount of fabric adhering after the explosion of a balloon it was possible to calculate the lift in advance. Each balloon would then be so inflated that after an assigned number had burst, the instrument and the remaining balloons would be in equilibrium. In this manner it was found possible to cause a flight to "level off" and to float at a high elevation.

The counters were standardized by operating each set immediately before the flight at a fixed distance from a stand-

[4] T. H. Johnson and S. A. Korff, *Terr. Mag.*, **44**, 23 (1939).
[5] T. H. Johnson, *Rev. Sci. Inst.*, **9**, 218 (1938).
[6] T. H. Johnson and S. A. Korff, *Rev. Sci. Inst.*, **10**, 82 (1939).

ard radium source, the radiation from which produced a counting rate of the same order as that encountered in the stratosphere. All comparisons between flights were made on the basis of this standardization. The counting rate observed at any time during a flight was divided by the "standard" counting rate of the apparatus, yielding a "calibrated" rate.

The intensity altitude curve thus obtained should not be compared directly with similar curves obtained with electroscopes, without applying the corrections due to the differences in geometry, which have been discussed by Korff and Danforth.[7] Such differences arise since the counting rate obtained with counters of high efficiency depend on geometry, while electroscope observations do not, and since also the radiation has a different angular distribution of intensity at different altitudes.

The flights made during the day employed instruments built into boxes made of $\frac{1}{4}$ inch balsa wood, painted black externally. These were enclosed in a double cellophane bag. Following Regener, solar radiation was used in this manner to keep the instrument warm. The temperature inside the box was measured and was found to remain within $\pm 15^\circ$ C. of room temperature during the flight. The record (pressure, altitude and temperature) obtained in a typical daytime flight is shown in Fig. 1. It will be seen that the temperature showed some fluctuations during the flight but at no time departed from the initial value by any large amount.

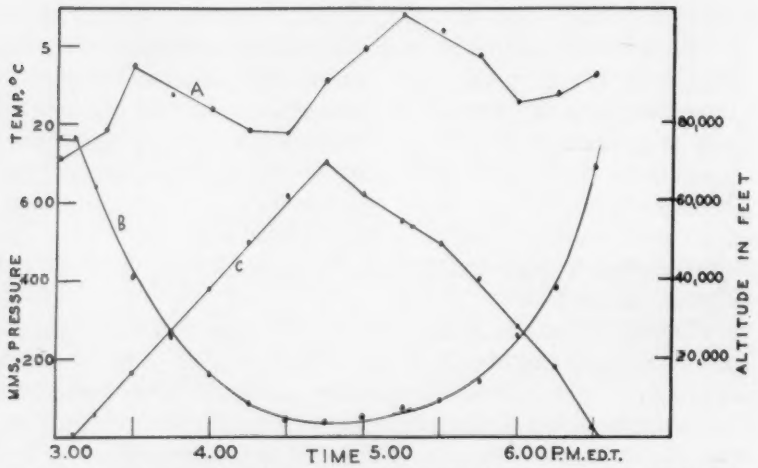
This arrangement was not suited to night flights, since in the absence of solar radiation the instrument would freeze. For night flights the balsa wood box was surrounded by a layer of Kapok about two inches thick, held in a cloth envelop, with the double cellophane bag over the whole as a windbreak. In addition, a heater was provided inside the apparatus. This consisted of a supply of "Thermat" powder, which produces heat when wet. Over this was placed a water reservoir with a small leak at the bottom and a few cc. of air at the top. As the apparatus ascended, and the atmospheric pressure decreased, the air forced the water drop by drop onto the Thermat powder. With this arrangement,

[7] S. A. Korff and W. E. Danforth, JOUR. FRANK. INST., **228**, 159 (1939).

the set continued to give signals for about three hours after a night takeoff.

The flights were released from Swarthmore, Pennsylvania, and were found to drift northeast. The geomagnetic latitude

FIG. 1.



A. Instrument temperature, *B*, air pressure and *C*, altitude curves of a typical flight, during the day. The temperature fluctuated somewhat, but never departed far from the average value at 15° C. The altitude curve rises linearly to its peak. The descent is less regular.

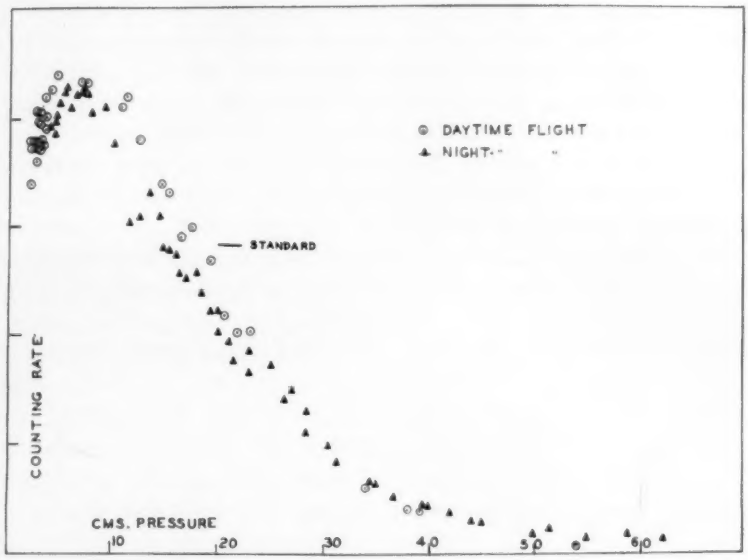
at which the determinations were made may therefore be taken as $53 \pm 1°$ North. The flights were made between August 9th and November 14th, 1938. Since the first and fourth in the series were made during the day and the second and third at night, effects due to long period variations in the intensity are minimized.

3. OBSERVATIONS.

The counting rates obtained in the four flights, two made during the day and two during the night, are presented in Fig. 2. The counting rates are plotted against pressure, after having been divided by the rate obtained with the radium standard just before takeoff. The points are plotted for each of the four flights independently, and the accuracy of the comparison may be judged by seeing how well all the points determine a single curve. Each point is based on the number of counts recorded in a four minute interval. The standard

deviation for the points near the top of the curve is about 1 per cent., while those at lower elevations have of course correspondingly lower precision. It will be seen that, at the top of the curve the points obtained at night lie about 1.5

FIG. 2.



Day and night intensities of the cosmic radiation. Counting rates obtained during the day and the night, observed as a function of altitude. The night time intensities are lower than the daytime values, but by less than the experimental uncertainty.

per cent. below those obtained during the day. The amount of this difference, however, is nearly equal to the experimental error, and hence cannot be regarded as established with certainty.

The flights reached a maximum altitude of 80,800 feet, at which level the instrument was at a depth of about 0.3 meters of water equivalent or 30 grams, below the top of the atmosphere. It can be stated that at this level, no difference between daytime and night intensities as large as 2 per cent. exists, but that the observations suggest that the night time intensity may be some 1.5 per cent. below that during the day.

4. DISCUSSION.

In a previous flight,[4] our apparatus was floating at 66,000 feet when an intense solar flare took place, accompanied by a radio fadeout. No increase in the counting rate as great as the experimental uncertainty of 2 per cent. took place which could be correlated with the flare. Yet sufficient ionization was produced by the flare at a higher level to cause a radio fadeout. The result was analyzed on the assumption that the ionizing radiation from the flare might be of the nature of X-radiation, and it was shown that the mass absorption coefficient must lie between 0.1 and 25 per gram.

Let us now consider the problem of the diurnal effect, on the assumption that the difference between daytime and nighttime intensities is real and as large as the experimental error permits, namely 1.5 per cent. at a depth of 30 grams of air, and further, that this effect is due to a penetrating ionizing radiation from the sun. The walls of the measuring instrument correspond to about 1 cm. water equivalent, and hence may be neglected. If the initial intensity of the solar component be I_0 ions per cc. per atm. per sec. in standard air, at the top of the atmosphere, and if we consider radiation in the spectral region subject to mass absorption, then at a depth x in the atmosphere the intensity I will be given by:

$$I = I_0 e^{-\alpha x} \tag{1}$$

for solar radiation incident vertically, where α is the mass absorption coefficient. If the radiation is incident at an angle θ, the equivalent path will be $x \sec \theta$. The observations show that at a depth $x = 30$ grams the intensity I must be less than $0.015M$, where M is the intensity of the total cosmic radiation at that level, which from Millikan's determination [8] we may take as of the order of 300 ions per cc. per atm. per sec. Hence (1) becomes:

$$I_0 e^{-30\alpha} \leq 4.5 \text{ ions.} \tag{2}$$

This relation represents the upper limit to the intensity I_0 at the top of the atmosphere of any radiation of absorption coefficient α originating in the sun. While the experiment cannot establish the entire absence of a solar component, it

[8] I. S. Bowen, R. A. Millikan and H. V. Neher, *Phys. Rev.*, **53**, 855 (1938).

does permit a definite limit to be set by eq. 2, to the maximum amount of any solar contribution to the ionization at 25 kms., due to photons in that spectral region in which the mass-absorption laws are valid.

Consider a specific example. It is well known from cascade theory and from the intensity measurements at high elevations that the cosmic ray intensity at the top of the atmosphere must be about 20 ± 5 ions. Hence we conclude from eq. 2., that an X-radiation of solar origin equal to the total primary cosmic ray intensity and with an α of 0.05 (corresponding to X-rays of about 0.07 A.U.) would be necessary to produce the observed effect. While the possibility of a solar component of this character cannot be excluded by the experiment, it should be pointed out that it should lead to a larger diurnal effect at higher elevations still, and further that for a softer radiation the corresponding I_0 would be greater yet.

Another possible source of a diurnal effect has been suggested by Vallarta.[9] He has pointed out that if the sun has a magnetic field of such magnitude as astrophysical considerations permit, the effect of this field would be to produce a variation of 1 or 2 per cent. between day and night intensities in the softest portion of the incoming radiation. Such soft radiation would presumably not penetrate the atmosphere to sealevel, and the diurnal effect would therefore only be manifest at higher elevations. At the latitude at which these flights were made, the LeMaitre-Vallarta function[10] is about 0.2, corresponding to a limiting energy of 2.5 Bev. for vertically incident rays or somewhat less for those from the eastern horizon. Since the difference, if any, is evident only near the top of the curve, it appears reasonable to ascribe the effect to this cause.

The author wishes to acknowledge the helpful cooperation of T. H. Johnson in making these flights. Thanks are due Mr. Roy Prince for assistance. The observations were supported by the Carnegie Institution of Washington.

[9] M. S. Vallarta, Proc. Chicago Cosmic Ray Symposium (1939).

[10] T. H. Johnson, *Revs. Mod. Phys.*, **10**, 219 (1938).

Fire Trench Digger Does Work of Many Men.—The United States Forest Service has made important advances in scientific fire fighting this year. They center mainly about such modern devices as airplanes and high-powered chemicals. But the average man on the fire line is likely to name as the most outstanding recent development a contrivance called, after its inventor, a Bosworth trencher. In fighting forest fires the machine is used to dig a flat trench or ditch in advance of a fire or to turn the flank of the flames. This trench will be at least a foot wide and deep enough to remove all leaf mold or other inflammable material. Along this line the fire fighters form to put out small fires that may jump the trench, or to start a backfire. The new trencher, devised by Jim Bosworth, assistant supervisor of the Kauiksu National Forest in Idaho, and perfected after much experiment and suggestion, will dig 50 or more feet of trench a minute, depending upon the terrain and the strength and skill of the operators, and may do the work of as many as 300 men. It has a wheelbarrow type of frame with a heavy bicycle wheel to carry the load. A small two-cylinder engine with a power shaft reaching groundward is suspended between the handles and drives a series of iron bars or "hammers" that swing from a central hub and throw the soil to one side. The trencher weighs 96 pounds. A harness of web straps enables the man who pushes it to carry part of the weight on his shoulders. In favorable country one man can push the trencher with good effect, but a towing bracket is provided so that one or more can aid by pulling where the terrain is tough.

R. H. O.

Aeronautical Research Laboratory.—Moffett Field, near Sunnyvale, California, has been selected by the National Advisory Committee for Aeronautics as the site for the new aeronautical research laboratory authorized in the Third Deficiency Act approved August 9, 1939. Fifty-four sites were brought to the Committee's attention within the time limit specified by law. Careful and impartial consideration was given to the merits of each site in an effort to make the best possible selection in the national interests without regard to the fact that the Committee had previously recommended the Sunnyvale site.

R. H. O.

THE THEORY AND APPLICATION OF EXTENDED SURFACE THERMOCOUPLES.

BY

HOWARD EMMONS, M.E., M.S., Sc.D.

In the widespread application of thermocouples to the measurement of temperature, care should be taken to put the junctions in isothermal regions. The most important step to insure no temperature variations along a junction is to make the junction as small as possible. In some cases, however, as in heat transfer research, it is sometimes difficult or impossible to make junctions sufficiently small compared to the spacial variations of temperature. It is desirable to know, at least qualitatively, just what the thermocouple reading means in terms of the temperatures actually existing along the junction.

1. THE GENERAL PROBLEM OF THE EXTENDED SURFACE THERMOCOUPLE.

By an extended surface thermocouple is meant one in which one of the junctions is so extensive that appreciable temperature differences occur between various parts of that surface. Figure 1 illustrates the general problem. A mass of metal A is joined along S to a metal B'.* Thermal currents flowing in the two metals cause temperature gradients along S. If the dimensions of the crystals of metals A and B' are small compared to the dimensions of the junction, the law of Magnus can be assumed.[1] This law states that a voltage difference "e" exists between metal A and B' across the junction, dependent only upon the temperature T of the junction at the point considered. Since the temperature varies over S, e will also be a function of position on S.

If we measure temperature from that of the reference junction J, the relation between e and T is given by

$$e = AT + BT^2 + \cdots, \qquad 1$$

* All primed quantities refer to metal B'.

[1] Bridgman, P. W., "The Thermodynamics of Electrical Phenomena in Metals."

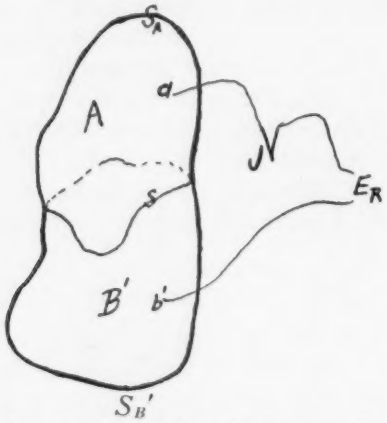
where A, B, etc. are constants. Since BT^2 and succeeding terms are small for moderate temperature ranges, the simpler relation

$$e = AT \qquad 2$$

will be used in the remainder of this analysis.

The variation of the voltage difference e along S will cause electric currents to flow in A and B'. When lead wires of metals A and B' are attached at points a and b', respectively (see Fig. 1), then the voltage difference E_R which

FIG. 1.



General case of extended surface thermocouple.

appears between them will be the result of the resistance drops in A and B' as well as the thermoelectric effect at the junction. The voltage E_R will correspond to a temperature T_R by the equation 2 which will be some kind of an average of the temperatures along S. To determine just what this average will be, we apply the laws of electrical conduction to the masses A and B'.

The voltage distribution in a homogeneous mass of metal whose resistance is constant is given by LaPlace's equation.

$$\begin{array}{ll} \text{For metal } A & \Delta E = 0 \\ \text{For metal } B' & \Delta E' = 0, \end{array} \qquad 3$$

where $\Delta = \dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2}$ in rectangular coördinates. The following boundary conditions must be satisfied.

For E, the current normal to S_A must be zero.

$$i_{n_A} = \frac{1}{r}\frac{\partial E}{\partial n_A} = 0. \qquad \text{a}$$

For E', the current normal to S_B' must be zero.

$$i_{n_B'} = \frac{1}{r'}\frac{\partial E'}{\partial n_{B'}} = 0. \qquad \text{b}$$

(4)

The voltage difference across the junction S must be the arbitrary thermoelectric voltage difference given by equation 2, in terms of the junction temperature. Thus

$$E - E' = e, \qquad 5$$

a function of position on S. The current flowing out of metal A at the junction S flows into metal B' at the same point. Therefore

$$i_{n_A} + i_{n_B'} = 0 \quad \text{or} \quad \frac{1}{r}\frac{\partial E}{\partial n_A} + \frac{1}{r'}\frac{\partial E'}{\partial n_{B'}} = 0. \qquad 6$$

For present purposes, no attempt to solve the general case need be made, since most thermocouples usually used can be treated with sufficient accuracy in simplified forms.

2. RECTANGULAR SLABS WITH A COMMON EDGE AS JUNCTION.

Suppose that two rectangular slabs of metal A and B' form a thermocouple junction along an edge (see Fig. 2). If no temperature variations occur perpendicular to the page, the problem is reduced to one in two dimensions. We thus have for E,

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} = 0 \qquad 7$$

with the boundary conditions along the free edges;

$$\begin{array}{llll} \text{at} & x = 0 & i_x = 0 \quad \text{or} & \left.\dfrac{\partial E}{\partial x}\right|^{x=0} = 0 \qquad \text{a} \\ \text{at} & x = c & i_x = 0 \quad \text{or} & \left.\dfrac{\partial E}{\partial x}\right|^{x=c} = 0 \qquad \text{b} \\ \text{at} & y = b & i_y = 0 \quad \text{or} & \left.\dfrac{\partial E}{\partial y}\right|^{y=b} = 0 \qquad \text{c} \end{array} \qquad 8$$

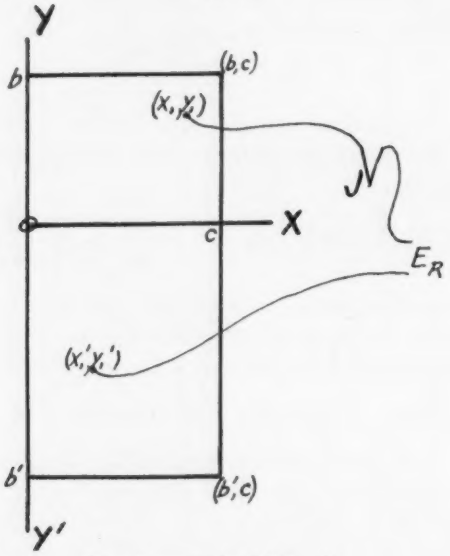
Similar equations apply to E', while E and E' are related along the junction $y = y' = 0$ by

$$E\big|_{y=0} - E'\big|_{y'=0} = e \qquad \text{a}$$

$$\text{and} \qquad \frac{1}{r}\frac{\partial E}{\partial y}\bigg|_{y=0} + \frac{1}{r'}\frac{\partial E'}{\partial y'}\bigg|_{y'=0} = 0 \qquad \text{b} \qquad \Big\} 9$$

"e" in equation 9a is related to the arbitrary temperature along the junction by equation 2, and is therefore to be

FIG. 2.



General rectangular slab junction.

taken as a continuous, bounded function of x. For metal A, the solution of 7 satisfying 8, is the Fourier Series.

$$E = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \operatorname{Cos} n\pi \frac{x}{c} \operatorname{Cosh} n\pi \frac{b-y}{c}. \qquad \text{a}$$

While for metal B' by symmetry,

$$E' = \frac{a_0'}{2} + \sum_{n=1}^{\infty} a_n' \operatorname{Cos} n\pi \frac{x'}{c} \operatorname{Cosh} n\pi \frac{b'-y'}{c}. \qquad \text{b} \qquad \Big\} 10$$

By substituting equations 10 into the boundary conditions of equations 9, expanding e into a half range Fourier Series

in Cosines, and solving for the a_n and a_n' we get

$$\left.\begin{aligned} a_n &= \frac{2r}{c}\frac{\int_0^c e \operatorname{Cos} n\pi \frac{x}{c}\,dx}{\operatorname{Sinh} n\pi \frac{b}{c}\left\{\frac{r}{\operatorname{Tanh} n\pi \frac{b}{c}} + \frac{r'}{\operatorname{Tanh} n\pi \frac{b'}{c}}\right\}} \qquad n \neq 0 \quad \text{a} \\ a_n' &= -\frac{2r'}{c}\frac{\int_0^c e \operatorname{Cos} n\pi \frac{x}{c}\,dx}{\operatorname{Sinh} n\pi \frac{b'}{c}\left\{\frac{r}{\operatorname{Tanh} n\pi \frac{b}{c}} + \frac{r'}{\operatorname{Tanh} n\pi \frac{b'}{c}}\right\}} \qquad n \neq 0. \quad \text{b} \end{aligned}\right\} 11$$

For $n = 0$

$$a_0 - a_0' = \frac{2}{c}\int_0^c e\,dx. \qquad \text{c}$$

We can now find out just what kind of an average temperature would be read by fastening two lead wires of metals A and B' from a reference junction and potentiometer to arbitrary points of the two strips, x_1, y_1 and x_1', y_1'. It is essential that the thermoelectric voltage be measured with no current flow since the above solution for the currents in the slabs supposes no current losses at the points of attachment of the wires.

2-A. GENERAL CASE OF RECTANGULAR SLABS. VOLTAGE MEASURED AT x_1y_1, $x_1'y_1'$ FIG. 2.

The voltage at points (x_1, y_1) and (x_1', y_1') are given by equations 10a and b with the coördinates of these points substituted. The voltage as read by a potentiometer would thus be

$$E_R = E - E' = \frac{a_0 - a_0'}{2} + \sum_{n=1}^{\infty}\left\{ a_n \operatorname{Cos} n\pi \frac{x_1}{c} \operatorname{Cosh} n\pi \frac{b - y_1}{c} - a_n' \operatorname{Cos} n\pi \frac{x_1'}{c} \operatorname{Cosh} n\pi \frac{b' - y_1'}{c} \right\}. \qquad 12$$

On substitution of the coefficients from 11 this becomes

$$E_R = \frac{1}{c}\int_0^c e\,dx + \frac{2}{c}\sum_{n=1}^{\infty} \frac{\int_0^c e \operatorname{Cos} n\pi \frac{x}{c}\,dx}{\left\{\frac{r}{\operatorname{Tanh} n\pi \frac{b}{c}} + \frac{r'}{\operatorname{Tanh} n\pi \frac{b'}{c}}\right\}} \times \left\{\frac{r \operatorname{Cos} n\pi \frac{x_1}{c} \operatorname{Cosh} n\pi \frac{b - y_1}{c}}{\operatorname{Sinh} n\pi \frac{b}{c}} + \frac{r' \operatorname{Cos} n\pi \frac{x_1'}{c} \operatorname{Cosh} n\pi \frac{b' - y_1'}{c}}{\operatorname{Sinh} n\pi \frac{b}{c}}\right\}. \quad 13$$

The voltage read at the lead wires is thus the arithmetic average thermoelectric voltage of the junction plus a term depending upon, among other things, the thermoelectric voltage variation along the junction.

Since the series of equation 13 converges absolutely, it can be put in the following form,

$$E_R = \frac{1}{c}\int_0^c we\,dx, \quad 14$$

where

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{1}{\left\{\frac{r}{\operatorname{Tanh} n\pi \frac{b}{c}} + \frac{r'}{\operatorname{Tanh} n\pi \frac{b'}{c}}\right\}} \times \left\{\frac{r \operatorname{Cos} n\pi \frac{x_1}{c} \operatorname{Cosh} n\pi \frac{b - y_1}{c}}{\operatorname{Sinh} n\pi \frac{b}{c}} + \frac{r' \operatorname{Cos} n\pi \frac{x_1'}{c} \operatorname{Cosh} n\pi \frac{b' - y_1'}{c}}{\operatorname{Sinh} n\pi \frac{b'}{c}}\right\}. \quad 15$$

E_R is thus seen to be a weighted average of the thermoelectric voltage along the junction. It is important to note that the weighting factor w is independent of the particular variation of the thermoelectric voltage which may occur.

Combining equation 2 and equation 14 we have

$$T_R = \frac{1}{c}\int_0^c wTdx. \qquad 16$$

We note several properties of equation 16.

1. If $w = 1$, the temperature indicated by the extended surface thermocouple would be

$$T_R = \frac{1}{c}\int_0^c Tdx, \qquad 17$$

which is the arithmetic average junction temperature. *In general the indicated temperature will not be the arithmetic average temperature but a weighted average temperature.*

2. By integration of equation 15 we get

$$\frac{1}{c}\int_0^c wdx = 1. \qquad 18$$

Thus if the entire extended surface thermocouple junction is at temperature T_0 equation 16 gives

$$T_R = T_0\frac{1}{c}\int_0^c wdx = T_0, \qquad 19$$

as is to be expected from physical reasoning.

3. If the reference junction temperature is increased by T_j degrees, the reading of the extended surface thermocouple would be

$$T_R' = \frac{1}{c}\int_0^c w(T - T_j)\,dx = \frac{1}{c}\int_0^c wTdx - \frac{T_j}{c}\int_0^c wdx = T_R - T_j. \qquad 20$$

Thus, as is to be expected, changing the reference junction temperature, causes an equal change in the indicated tem-

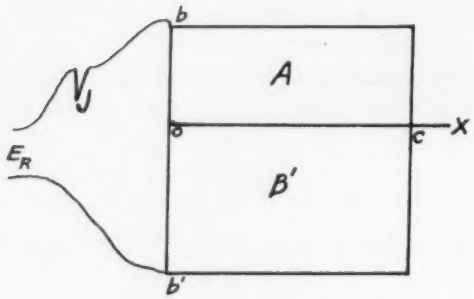
perature. (The original reference junction temperature was set equal to 0, see equation 2.)

2B. SPECIAL CASE OF RECTANGULAR SLABS.

Both voltage wires attached at same end (0, b) and (0, b'). See Fig. 3. w from equation 15 reduces to

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{\dfrac{r}{\operatorname{Sinh} n\pi \dfrac{b}{c}} + \dfrac{r'}{\operatorname{Sinh} n\pi \dfrac{b'}{c}}}{\dfrac{r}{\operatorname{Tanh} n\pi \dfrac{b}{c}} + \dfrac{r'}{\operatorname{Tanh} n\pi \dfrac{b'}{c}}} \operatorname{Cos} n\pi \frac{x}{c}, \qquad 21$$

FIG. 3.



Special case of rectangular slab junction.

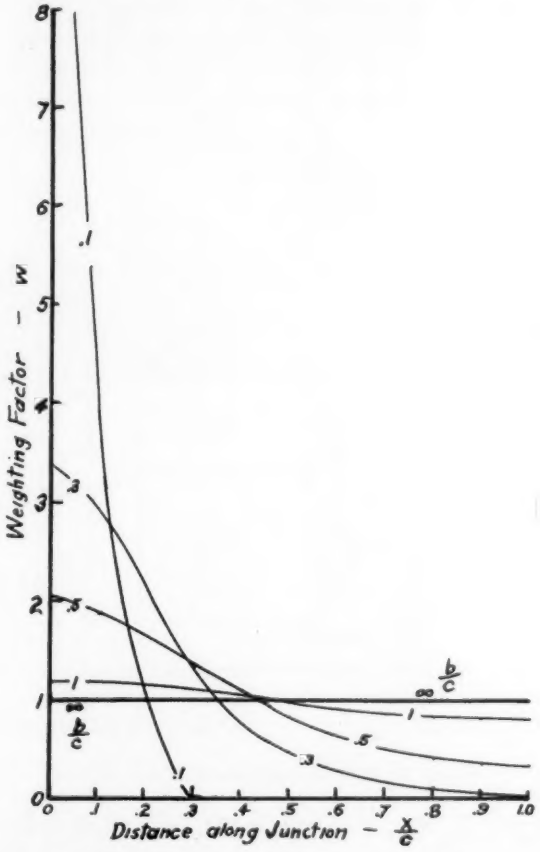
for $b = b'$

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{\operatorname{Cos} n\pi \dfrac{x}{c}}{\operatorname{Cosh} n\pi \dfrac{b}{c}}. \qquad 22$$

The weighting function given by this equation is plotted in Fig. 4 for various ratios of width to length $\frac{b}{c}$. It is seen that if the metal width is greater than the junction length, all points of the junction are of approximately equal importance in their effect on the indicated temperature, i.e. temperature indicated is practically the arithmetic average junction temperature. For long narrow junctions, the temperature indi-

cated by the extended surface thermocouple becomes essentially that of the end to which the leads are attached. It is noteworthy that in this case the weighting depends only upon the width of the slabs and is entirelv independent of the

FIG. 4.



Weighting factor for junction of Fig. 3 with $b = b'$.

electric and thermoelectric properties of the metals of which the junction is made.

2C. SPECIAL CASE OF RECTANGULAR SLABS.

Voltage leads attached at opposite ends (c, b) and (o, b'), see Fig. 5.

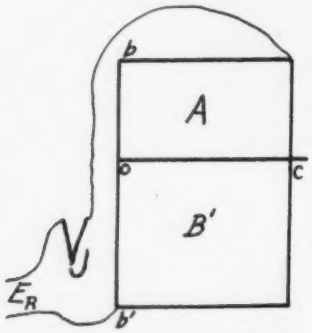
The weighting factor w—equation 15 becomes

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{(-1)^n \dfrac{r}{\operatorname{Sinh} n\pi \dfrac{b}{c}} + \dfrac{r'}{\operatorname{Sinh} n\pi \dfrac{b'}{c}}}{\dfrac{r}{\operatorname{Tanh} n\pi \dfrac{b}{c}} + \dfrac{r'}{\operatorname{Tanh} n\pi \dfrac{b'}{c}}} \operatorname{Cos} n\pi \frac{x}{c}. \qquad 23$$

For $b = b'$

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{\left\{(-1)^n + \dfrac{r'}{r}\right\} \operatorname{Cos} n\pi \dfrac{x}{c}}{\left\{1 + \dfrac{r'}{r}\right\} \operatorname{Cosh} n\pi \dfrac{b}{c}}. \qquad 24$$

FIG. 5.



Special case of rectangular slab junction.

The weighting factor given by this equation is plotted in Fig. 6 for various width-length ratios $\frac{b}{c}$. Since the ratio of resistivities influence the weighting, Fig. 6 is quantitatively correct only for the value $\frac{r'}{r} = 0.1$ used in its calculation. The approximate value of $\frac{r'}{r}$ for several common combinations of thermocouple metals is given in Table 1.

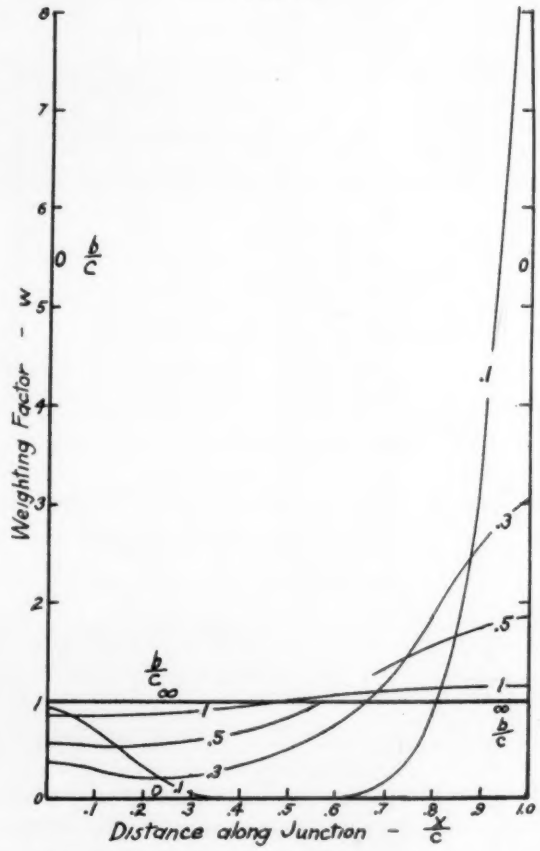
Figure 6 shows that for relatively wide thermocouples all points of the extended surface junction are approximately

TABLE I.

	r'/r
Cu-Const	.052
Fe-Const	.37
Pt-Pt-Ir	.055
Chromel-Alumel	.30

equally weighted, while for narrow junctions, the temperatures at the two ends are weighted more heavily then those in the center. In any case, the temperature at the end where the lead is attached to the metal of highest resistivity is weighted the most heavily.

FIG. 6.

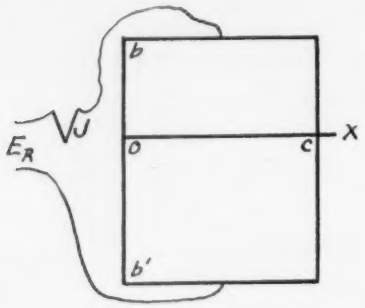


Weighting factor for junction of Fig. 5 with $b = b'$ and $r'/r = .1$.

2D. SPECIAL CASE OF RECTANGULAR SLABS.

Voltage leads attached at center of sides $\left(\frac{c}{2}, b\right)$ and $\left(\frac{c}{2}, b'\right)$, see Fig. 7. The weighting factor w—equation 15

FIG. 7.



Special case of rectangular slab junction.

simplifies to

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{\dfrac{r}{\operatorname{Sinh} n\pi \dfrac{b}{c}} + \dfrac{r'}{\operatorname{Sinh} n\pi \dfrac{b'}{c}}}{\dfrac{r}{\operatorname{Tanh} n\pi \dfrac{b}{c}} + \dfrac{r'}{\operatorname{Tanh} n\pi \dfrac{b'}{c}}} \operatorname{Cos} \frac{n\pi}{2} \operatorname{Cos} n\pi \frac{x}{c}. \qquad 25$$

For

$$w = 1 + 2\sum_{n=1}^{\infty} \frac{\operatorname{Cos} \dfrac{n\pi}{2} \operatorname{Cos} n\pi \dfrac{x}{c}}{\operatorname{Cosh} n\pi \dfrac{b}{c}}. \qquad 26$$

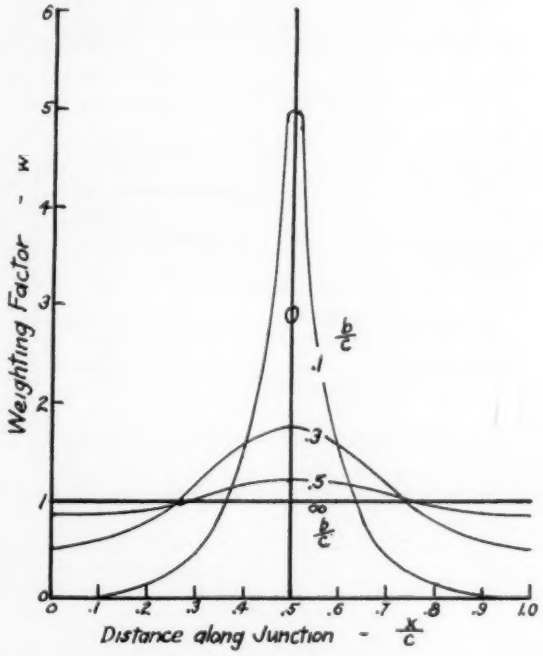
Figure 8 shows the weighting factor from equation 26 for various width-length ratios $\frac{b}{c}$. In this case too, relatively wide thermocouples weight all parts of the junction about equally while narrow junctions read essentially the temperature at the place where the wires are joined.

CONCLUSIONS FOR THE RESPONSE OF RECTANGULAR THERMOCOUPLE JUNCTIONS.

1. For short-wide junctions ($c \leq b \approx b'$, Fig. 2) the temperature at all points of the junction are about of equal importance in their effect on the indicated temperature.

2. For long-narrow junctions ($c > b \approx b'$, Fig. 2) the temperature at the points of the junction near where the lead

FIG. 8.



Weighting factor for junction of Fig. 7 with $b = b'$.

wires are fastened have more effect on the indicated temperature than more distant points.

3. For long-narrow junctions with both lead wires attached at the same end, the temperature indicated is essentially that of the end to which the leads are connected.

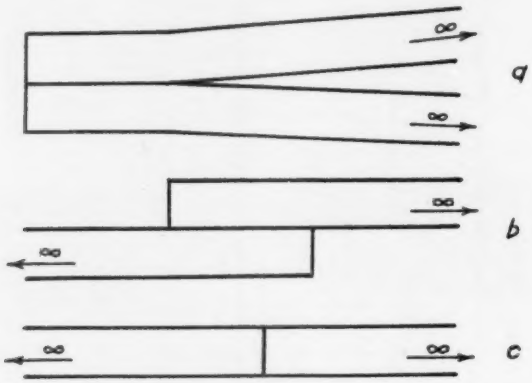
4. For long-narrow junctions with the leads attached at opposite ends, the temperature indicated is essentially a weighted average of the temperature at the two ends.

3. OTHER JUNCTION SHAPES.

The rectangular junctions considered so far are only approximations to the junctions as normally used. The common junction shapes are illustrated in Fig. 9.

It is instructive to carry through the solution for case "*a*," Fig. 9, and to compare it with rectangular slabs, Case 2*b*, Fig. 3.

FIG. 9.



Some common thermocouple junction forms.

Equations 15 and 16 apply immediately to case *c*, Fig. 9, if we let $b, b', y, y' \to \infty$,

$$T_R = \frac{1}{c}\int_0^c T dx, \qquad 27$$

which is seen to be the arithmetic average of the junction temperature.

Examining the complex function

$$Z = \mathrm{Sin}^{-1}\left\{\frac{\mathrm{Sinh}\,\frac{\pi Z'}{2b}}{\mathrm{Sinh}\,\frac{\pi c}{2b}}\right\}, \qquad 28$$

we see that it transforms the strip from 0 to $\frac{\pi}{2}$ in the Z plane

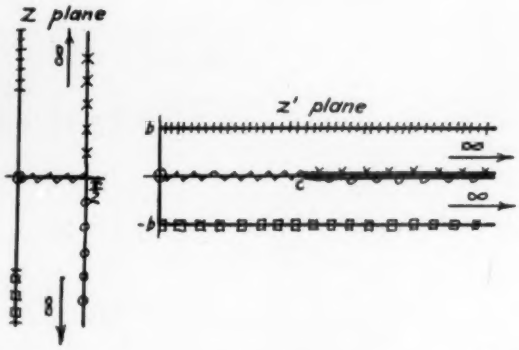
into the desired shape of Fig. 9*a* in the Z' plane. See Fig. 10.

Thus the solution for the voltage distribution in Fig. 9*c* can be transformed to the solution for the voltage distribution in Fig. 9*a*. From this voltage distribution, the weighting factor for the new case can be derived.

In general, if the voltage E_Z is read at points corresponding to those at which E_w is read, the transformed weighting factor is given by the relation

$$w_w(w_1, w_2, w_3) = \frac{C_w}{C_Z} f'(w) w_Z(f(w_1), f(w_2), f(w_3)), \qquad 29$$

FIG. 10.



The transformation of case *c*, Fig. 9, into case *a*, Fig. 9, by $z = \sin^{-1}\left\{\frac{\sinh \frac{\pi z'}{2b}}{\sinh \frac{\pi c}{2b}}\right\}$.

Marks indicate corresponding lines.

where $w_w(w_1, w_2, w_3)$ is the weighting factor in the w plane with measurements made at points w_1, and w_2. w_3 refers to points along the junction.

C_w is the length of the junction in the w plane.

C_Z is the length of the junction in the Z plane.

$f'(w)$ is the derivative of the transformation function $Z = f(w)$.

$w_Z(Z_1, Z_2, Z_3) = w_Z(f(w_1), f(w_2), f(w_3))$ is the weighting factor in the Z plane with measurements made at points Z_1 and Z_2. Z_3 refers to points along the junction.

This relation follows immediately from $Z = f(w)$ as follows,

$$T_{R_Z} = \frac{1}{C_Z}\int_{C_Z} w_Z(Z_1, Z_2, Z_3)T_Z\,dz$$

$$= \frac{1}{C_w}\int_{C_w}\left(\frac{C_w}{C_Z}\right) w_Z(f(w_1), f(w_2), f(w_3))T_w f'(w)\,dw$$

and, by definition of w_w,

$$T_{R_w} = \frac{1}{C_w}\int_{C_w} w_w(w_1, w_2, w_3)T_w\,dw,$$

but for thermoelectric voltage measured at corresponding points

$$T_{R_Z} = T_{R_w}.$$

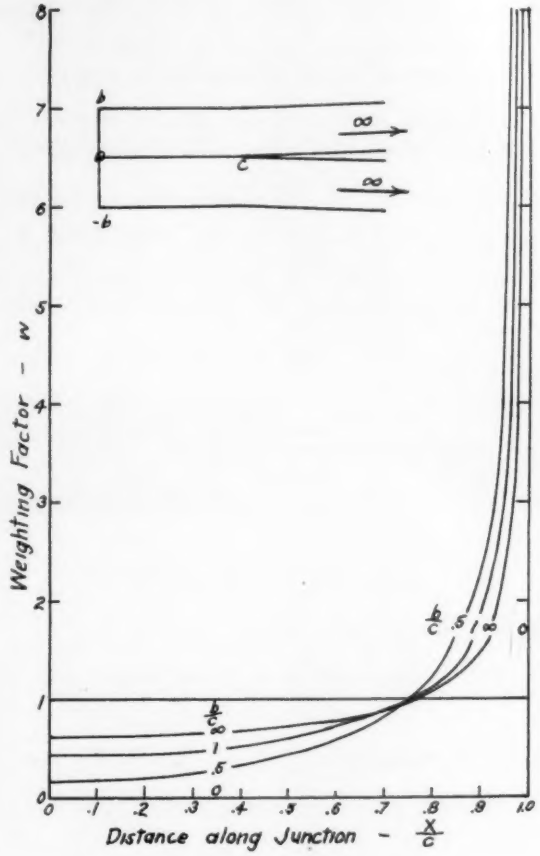
Thus since the above integrals are true for all functions T_w, we have equation 29.

For the Z plane of Fig. 10, $w_Z = 1$ by equation 27 and $C_Z = \frac{\pi}{2}$ by equation 28. Thus by equation 29

$$w_{Z'}(\infty, \infty, x') = \frac{2c}{\pi}f'(w) = \frac{c}{b}\frac{\operatorname{Cosh}\frac{\pi x'}{2b}}{\left\{\operatorname{Sinh}^2\frac{\pi c}{2b} - \operatorname{Sinh}^2\frac{\pi x'}{2b}\right\}^{\frac{1}{2}}}. \quad 30$$

Figure 11 shows this weighting factor plotted against distance along the junction for various ratios of width to length $\frac{b}{c}$. A comparison with Fig. 4 shows the modification produced in the simple rectangular junction theory by the more exact approximation to conditions actually used. One marked difference is to be noted. For the rectangular junctions, the indicated temperature approaches the arithmetic average as the junctions are made wider $\left(\frac{b}{c} \to \infty\right)$; while for the junction of Fig. 9*a*, the temperature at $x = c$ is always much more heavily weighted than any other point.

FIG. 11.



Weighting factor for junction of case *a*, Fig. 9.

For $\frac{b}{c} \to \infty$ equation 30 reduces to

$$w = \frac{2}{\pi} \frac{1}{\left\{1 - \left(\frac{x}{c}\right)^2\right\}^{\frac{1}{2}}}. \qquad 31$$

In general, the action of rectangular slab thermocouples indicates the qualitative characteristics of ordinary extended surface thermocouples. A quantitative modification may be

necessary, however. This quantitative modification will not be of major importance except at rëentrant angles of the junction.

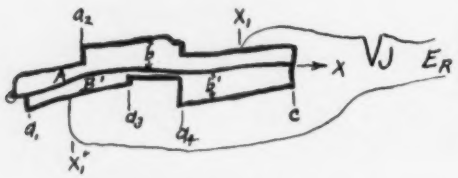
4. JUNCTIONS OF VARYING SECTIONS. FIG. 12.

Suppose the junctions are not of rectangular form but have varying sections. We will consider the case of

$$c \gg b, b'. \qquad 32$$

The voltage and current can be considered distributed uniformly across the metals A and B' so that the voltage distribution can be found by a one dimensional application of

FIG. 12.



General case of long narrow junction.

Ohm's and Kirchoff's law. Thus

$$\frac{dE}{dx} = iR, \quad \frac{dE'}{dx} = i'R', \quad \text{Ohm's law.} \qquad 33$$

$$i + i' = \text{Constant}, \qquad \text{Kirchoff's law,} \qquad 34$$

but no current flows from the end of the junction, $x = 0, c$,

$$i + i' = 0. \qquad 35$$

Substitute 33 into 35

$$\frac{1}{R}\frac{dE}{dx} + \frac{1}{R'}\frac{dE'}{dx} = 0. \qquad 36$$

The temperature along the junction causes, by equation 2, a voltage difference e

$$E - E' = e. \qquad 37$$

From 37 and 36

$$\frac{dE}{dx} = \frac{R}{R + R'}\frac{de}{dx}, \quad \frac{dE'}{dx} = -\frac{R'}{R + R'}\frac{de}{dx}. \qquad 38$$

Integrating

$$E = E(0) + \int_0^x \frac{R}{R + R'} \frac{de}{dx} dx,$$
$$E' = E'(0) - \int_0^x \frac{R'}{R + R'} \frac{de}{dx} dx. \qquad 39$$

Now if voltage readings are taken at x_1 and x_1', with $x_1 > x_1'$, see Fig. 12, we have

$$E_R = E(x_1) - E'(x_1') = E(0) - E'(0) + \int_0^{x_1} \frac{R}{R + R'} \frac{de}{dx} dx + \int_0^{x_1'} \frac{R'}{R + R'} \frac{de}{dx} dx \qquad 40$$
$$= e(x_1') + \int_{x_1'}^{x_1} \frac{R}{R + R'} \frac{de}{dx} dx.$$

Making use of equation 2 this becomes

$$T_R = T_{x_1'} + \int_{x_1'}^{x_1} \frac{R}{R + R'} \frac{dT}{dx} dx. \qquad 41$$

The temperature indicated by the thermocouple depends only upon the temperature and resistance of that portion of the junction between x_1', and x_1.

If $x_1' = x_1$, then $T_R = T_{x_1}$ 42

or the temperature at the point of attachment of the wires is read directly. Compare with Fig. 8 of which this is a limiting case for which $\frac{b}{c} \to 0$, $\frac{b'}{c} \to 0$.

Change the independent variable in 41 to $\eta = \frac{x - x_1'}{x_1 - x_1'}$ thus making the effective junction extend from 0 to 1.

$$T_R = T_0 + \int_0^1 \frac{R}{R + R'} \frac{dT}{d\eta} d\eta. \qquad 43$$

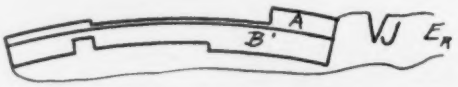
Suppose that the resistance R or R' or both are continuous except at $\eta = a_1, a_2, \cdots a_i, \cdots a_n$, see Fig. 12.

Integrate 43 by parts.

$$T_R = \frac{R_0'}{R_0 + R_0'} T_0 + \sum_{i=1}^{n} \left[\frac{R}{R + R'} \right]_{\eta_i+}^{\eta_i-} T_i + \frac{R_1}{R_1 + R_1'} T_1 - \int_0^1 \frac{d}{d\eta} \left(\frac{R}{R + R'} \right) T d\eta, \quad 44$$

where $\left[\frac{R}{R + R'} \right]_{\eta_i+}^{\eta_i-}$ is the decrease in the value of $\frac{R}{R + R'}$ across the discontinuity at η_i and the integral omits the points of discontinuity.

FIG. 13.



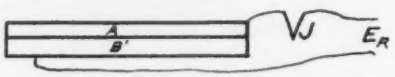
Special case of long narrow junction.

If R and R' are constant between each discontinuity, Fig. 13, equation 44 gives

$$T_R = \frac{R_0'}{R_0 + R_0'} T_0 + \sum_{i=1}^{n} \left[\frac{R}{R + R'} \right]_{\eta_i+}^{\eta_i-} T_i + \frac{R_1}{R_1 + R_1'} T_1. \quad 45$$

We note that only the temperature at a discontinuity of resistance has any effect upon the reading of the thermocouple.

FIG. 14.



Special case of long narrow junction.

If we further suppose that there are no discontinuities between the lead wires, with R and R' constant as in 45, we would read

$$T_R = \frac{R'T_0 + RT_1}{R + R'}. \quad 46$$

A thermocouple constructed as in Fig. 14 reads a weighted average of the temperature where the lead wires are attached.

Returning to equation 44, suppose that a thermocouple junction is constructed without any discontinuities and with $R_0 = R_1' = \infty$. Then

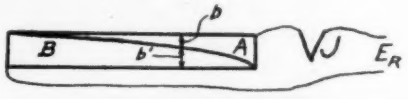
$$T_R = -\int_0^1 \frac{d}{d\eta}\left(\frac{R}{R+R'}\right) T d\eta. \qquad 47$$

With this expression it is possible to design a thermocouple junction which reads any desired weighted average of the temperatures along the junction. In particular, if it is desired to read the arithmetic average junction temperature, we have

$$T_R = \int_0^1 T d\eta = -\int_0^1 \frac{d}{d\eta}\left(\frac{R}{R+R'}\right) T d\eta. \qquad 48$$

Since this expression is to be true for all T, we can equate

FIG. 15.



Special case of long narrow junction. Reading arithmetic average temperature.

the integrands thus getting an equation for the resistance of the junctions,

$$\frac{d}{d\eta}\left(\frac{R}{R+R'}\right) = -1. \qquad 49$$

Integrate and set $R = \infty$ at $\eta = 0$ (note that we must also have $R' = \infty$ at $\eta = 0$ which is automatically satisfied):

$$\left.\begin{aligned} &\frac{R}{R+R'} = 1-\eta \\ \text{or} \quad &\frac{R}{R'} = \frac{1-\eta}{\eta}. \end{aligned}\right\} \qquad 50$$

A thermocouple pictured in Fig. 15 results. Equation 50 only specifies the ratio of R to R' so that one other condition can be imposed, as for example, $b + b' =$ a constant (Fig. 15).

GENERAL CONCLUSIONS FOR LONG NARROW THERMOCOUPLE JUNCTIONS.

1. Only the portion of the junction included between the wires to the cold junction and potentiometer have any effect on the indicated temperature. In particular if the lead wires are attached opposite each other on the junction only the junction temperature at that point is read.

2. The temperature at discontinuities of resistance, have special weighting depending upon the magnitude of resistance change.

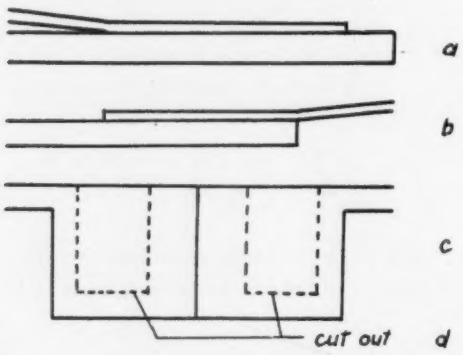
3. For junctions of uniform resistance, a weighted average of the temperatures at the points of attachment of the lead wires is recorded.

4. A junction can be designed to read any desired weighted average of the temperature along the junction.

EXPERIMENTAL VERIFICATIONS.

In 1931, Bailey [2] published some test results on various shapes of thermocouples. See Fig. 16. With temperature

FIG. 16.



Thermocouples tested by Bailey.

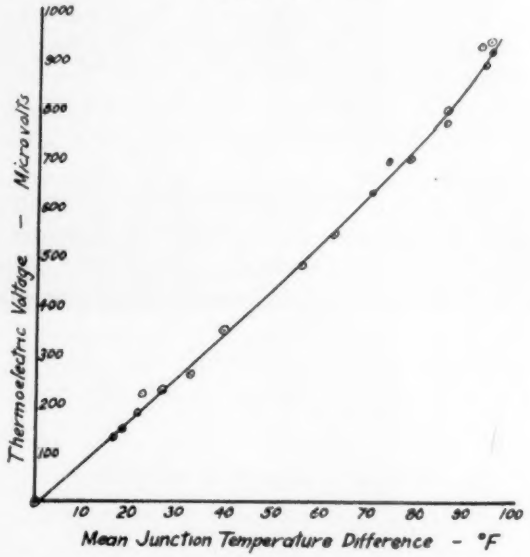
variations along the junctions of from 50° F. to 100° F., thermocouple, Fig. 16a, indicated the temperature at the lead end only (equation 42), Fig. 16b agreed with equation 46. Calculations with equations 15 and 16 using the test tempera-

[2] N. Bailey, "The Response of Thermocouples," *Mech. Eng.*, **53**, No. 11, 797 (1931).

ture variations for thermocouples Fig. 16 c and d agree with the read temperatures as follows.

Fig. 16c. Read 152.0° F.
Calculated weighted average, 157.5° F.
Fig. 16d. Read 157.0° F.
Calculated weighted average, 158.6° F.

FIG. 17.



Calibration of copper-nickel averaging tube thermocouple junction.

Considering that the test temperature distribution was measured at only 3 points, the agreement is very good.

For the determination of coefficients of heat transfer from flowing or condensing media to solid tubes, it is often desired to know the average surface temperature of the tubes. By an application of equation 50, it is possible so to construct a tube that one reading serves to determine the average tube temperature. Strictly speaking only the average junction temperature is read and a correction has to be made for the temperature drop from the tube surface to the junction.

A tube, $\frac{1}{2}''$ external diameter, 10″ long with $\frac{1}{10}''$ thick walls, of the best commercial grade of nickel, was carefully

turned down to the shape computed by equation 50. The additional condition on the resistance was chosen such that after the junction had been completed with copper it would be restored to its original uniform diameter. The copper was electroplated on the nickel tube starting with a basic plating solution and finishing with an acid plating solution.

To calibrate the tube, the temperature variation was obtained with various rates of film condensation of steam on its surface. The surface temperature variation was found by 4 copper construction thermocouples carefully set in the surface through holes from the inside.

The calibration curve thus obtained is shown in Fig. 17. The theory presented in this paper is thus well substantiated.

ACKNOWLEDGMENT.

This paper is taken, in part, from the appendix of a S.D. thesis presented to the Graduate School of Engineering of Harvard University and is published with permission.

ON THE GEOMETRY OF OPTICAL INDICATORS.*

BY

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The term "optical indicator" will be used here in its broad sense embracing all kinds of instruments in which one or more optical levers are incorporated. The advantage of the optical lever as a magnifying and recording element resides in its:

(*a*) Low inertia, the only mass being the mirror, the magnifying lever—the light beam—being without any mass;

(*b*) Attainability of a large ratio of magnification in one step with a single magnifying lever;

(*c*) Low value of backlash and friction, these being confined to the support of the mirror, while the rest of the magnifying system, the light beam and its recording end on the screen (or on light-sensitive film) are free of both backlash and friction.

CLASSIFICATION OF OPTICAL INDICATORS.

In virtue of these advantages optical indicators have a wide application in physics and engineering for the magnification and measurement of:

1. Small distances, such as inequalities (ridges and valleys) on a machined surface (profilograph); differences between two dimensions, as between a standard gage block and a piece to be compared with it (optical gage, comparator); change of dimension of a piece under stress or temperature influences (extensometer);

2. Small, rapid motions, such as vibration of a body (vibrometer, seizmograph) and strain (strain gage);

3. Rapidly varying pressures, forces, electrical currents and voltages. In these applications a converter has to be provided for transforming the quantity to be measured into

* Manuscript received March 1938.

small displacements which in turn can be measured by optical means. Examples of this group: optical pressure indicator, dynamometer, galvanometer, oscillograph.

According to the number of variables to be measured such optical indicators can be classified as:

(*A*) One-variable indicators, called "-meters," which measure only one variable on a graduated scale (e.g., extensometer, vibrometer, galvanometer);

(*B*) Two-variable indicators which represent on a screen, or on a photographic film, in a two-coördinata diagram, the interrelationship of two variables. If the representation is visual the proper term is "-scope" (e.g., vibroscope, oscilloscope). If the representation is a permanent photographic record the proper term is "-graph" (e.g., extensograph, vibrograph, oscillograph, torsiograph). The distinction between "-scope" and "-graph" is not always sharply drawn and in many cases the same instrument can be used for visual inspection as well as for photographic recording.

According to the purpose of the various applications the constructional features of the optical indicators show a wide diversity. The principles of the optical magnification, however, are common to all. The purpose of this paper is to analyze and elucidate the geometrical principles underlying the optical magnification and to discuss the requirements and desiderata for their most advantageous realization in actual instruments.

THE OPTICAL LEVER.

The basic element of optical indicators is the optical lever, Fig. 1, which in its essentials consists of (*a*) a light source *B* and means (aperture and lens) for producing a light beam *l*, (*b*) a mirror which in its point *M* intercepts and reflects the light beam and the position of which with reference to the light beam can be changed, (*c*) a screen *S* upon which the reflected light beam *p* impinges and produces a light spot *P*. Assuming the position of the incident beam constant there will correspond to every position of the mirror a definite position of the reflected beam *p* according to the two laws of reflection:

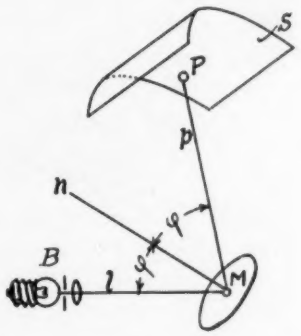
(1) The incident beam l, the normal n to the mirror surface at the point of incidence, and the reflected beam lie in one plane;

(2) The angle of incidence $\sphericalangle ln = \varphi$ is equal to the angle of reflection $\sphericalangle np = \varphi$.

KINEMATIC CONSIDERATIONS.

The mirror, as every rigid body, can have six degrees of freedom of motion. It can be readily visualized that the following three motions: rotation about the normal n and

FIG. 1.



Arrangement of Optical Lever. B = source of light; l = incident beam; M = point of impingement on mirror; n = normal to the mirror surface at the point of impingement; p = reflected beam; l, n and p lie in one plane; angle of incidence $\sphericalangle ln = \varphi$ equal to angle of reflection $\sphericalangle lp = \varphi$; S = screen; P = point of impingement of the reflected beam on the screen.

translation in two directions in the mirror plane, have no influence on the position of n, nor on that of p. Only the following three motions:

(a) translation along l,
(b) rotation about an axis intersecting n at point M,
(c) rotation about another axis intersecting n at point M,

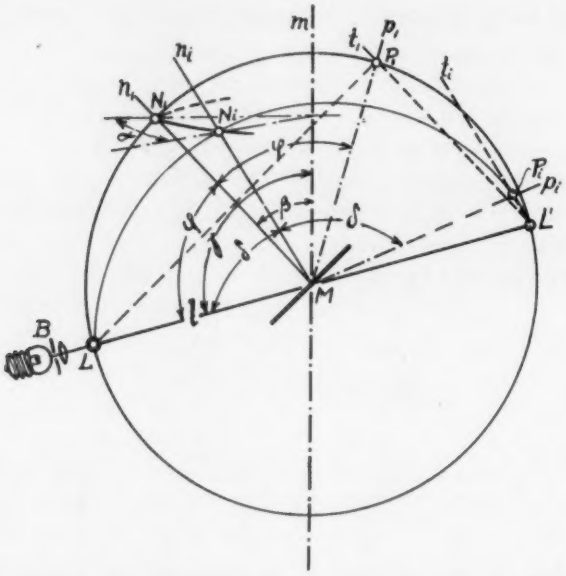
do influence the position of n and hence also the position of p.

If the mirror is constrained in such a manner that it can execute the three a, b, c, motions then it is termed an optical lever with three degrees of freedom, and the possible positions of n constitute a triple multitude of straight lines intersecting l,

and the corresponding positions of p constitute another triple multitude of straight lines intersecting l.

The motion (a), i.e., the translation along l results only in the translation of n and p parallel to themselves, hence has, in general, no great magnifying effect. Removing this freedom, i.e., fixing the M point renders the mirror an optical lever with two degrees of freedom, i.e., rotation of n about two axes

FIG. 2.



Optical lever with one degree of freedom of rotation about the m-axis. N_1, N_i = points of intersection of the mirror-normals n_1, n_i with the spherical screen; P_1, P_i = points of intersection of the reflected beams p_1, p_i with the spherical screen; the lines $t_1 \| n_1$ and $t_i \| n_i$ intersect the spherical screen in the P_1 and P_i points.

intersecting at M, which are not coincident with n. The possible positions of n will constitute a double multitude of straight lines radiating from the point M forming in their totality a solid cone body, and the corresponding positions of p will constitute another double multitude of straight lines radiating from the point M forming in their totality another solid cone body.

Removing one of these two freedoms renders the mirror an optical lever with one degree of freedom, i.e., rotation of n

about one single axis intersecting l and n at M. The possible positions of n will constitute a simple multitude of straight lines radiating from the point M forming in their totality a conical surface having its vertex at M, and the corresponding positions of p will constitute another simple multitude of straight lines radiating from the point M forming in their totality another conical surface having its vertex at M.

Our next purpose is to analyze the characteristics of the optical lever with one degree of freedom of rotation.

OPTICAL LEVERS WITH ONE DEGREE OF FREEDOM OF ROTATION.

In Fig. 2 is represented an optical lever with one degree of freedom of rotation of the mirror about the axis m. The attitude of the incident light beam is expressed by the angle $\gamma = \sphericalangle lm$, and the attitude of the mirror is expressed by the angle $\beta = \sphericalangle nm$. Assuming the l, M and m to be fixed in the plane of the paper, and the initial position of n to be also in the plane of paper, the rotation of the mirror is defined by the angle α, being the dihedral angle enclosed by the planes lm and nm. Evidently for a complete revolution of the mirror from $\alpha = 0$ to $\alpha = 360°$ the mirror normal will describe a circular conical surface with m as axis, with the vertex M and with the vertex angle 2β; the locus of corresponding p lines will be another conical surface, not necessarily circular, with the vertex M. The problem of the optical lever can be stated:

For a given pair of constant β and γ values find, for every possible position of n the corresponding p.

This problem can be solved by calculation, by defining the direction of n and p in spherical coordinates and by expressing the laws of reflection by equations. Or, it can be solved by construction, with the methods of descriptive geometry. Both of these methods involve laborious calculations or intricate geometrical constructions and do not give an insight into the interrelationships involved.

Therefore it is proposed to analyze this problem with the aid of a third method, based on simple considerations of plane and solid geometry, the results of which can be easily visualized and which will furnish all the data needed for the determination of the characteristics of any given optical lever.

For the purpose of this analysis we shall assume a spherical screen of arbitrary radius with M as center. This sphere intersects: (1) the incident beam l at point L and the extension of l at the opposite pole L'; (2) the mirror-normal n at point N, and (3) the reflected beam p at point P. The locus of the N points will be a circle. Assuming both faces of the mirror to be reflecting the n cone is extended beyond the vertex and there will be two N circles, one in the upper and the other in the lower hemisphere, in planes perpendicular to n valid for the upper and lower reflecting surface respectively. With these concepts and notations the problem can be re-worded as follows:

Assuming L constant find for every N_i point the corresponding P_i, and for every N-circle the corresponding P-curve.

From the above stated laws of reflection it follows that for corresponding pairs of N_i and P_i points:

(1*a*) The points LMN_iP_i lie in one plane:

(1*b*) The points L, N_i and P_i lie on the same great circle of the sphere;

(1*c*) For a given position of L all these LMN_i, P_i planes intersect in the common LML' diagonal;

(2*a*) The angle of incidence equals the angle of reflection, i.e.: $2 \sphericalangle LMN_i = \sphericalangle LMP_i$;

(2*b*) L and P_i are symmetrically situated with respect to MN_i as the axis of symmetry.

Depicting, in Fig. 3, one of the infinite number of MLN_iP_iL' great circles in the plane of the paper it is seen that the parallel t drawn from point L' with MN' intersects the great circle at the P_i point. Proof: The arc LP_i subtends the central angle $\sphericalangle LMP_i$ and also the inscribed angle $\sphericalangle LL'P_i = \sphericalangle LMN_i = \delta$. As a central angle is equal twice the inscribed angle subtending the same arc therefore

$$\sphericalangle LMP_i = 2 \sphericalangle LMN_i.$$

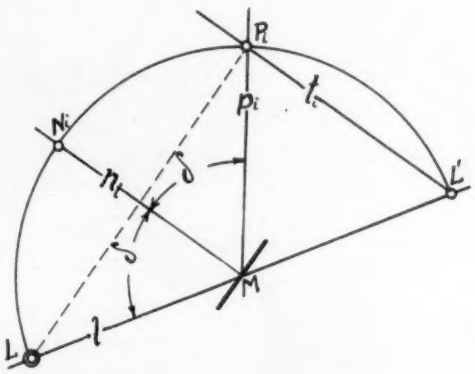
Other proof:

$$LP_i \perp MN_i \| L'P_i,$$
$$L'P_i \perp LP_i,$$
$$LM = ML'.$$

Hence P_i is symmetrical to L with respect to MN_i as axis of symmetry, and $2 \sphericalangle LMN_i = \sphericalangle LMP_i$, q.e.d.

The $L'P_i$ lines erected in their true position in space constitute in their totality a t-cone parallel and similar to the n-cone, with its vertex transposed to the L'-pole, and the totality of the P_i points (i.e., the spherical directrix of the p-cone) will be the intersection of the sphere with this t-cone. This represents the solution of our problem which can be stated in the following theorem, which may be called the *Theorem of Transposed Cone:*

FIG. 3.



Construction of a double angle on a great circle of the spherical screen. The line t erected at pole L' parallel with n intersects the great circle at P, for which $2 \sphericalangle LMN = \sphericalangle LMP_iP$ is also the image of L with reference to n as axis of symmetry.

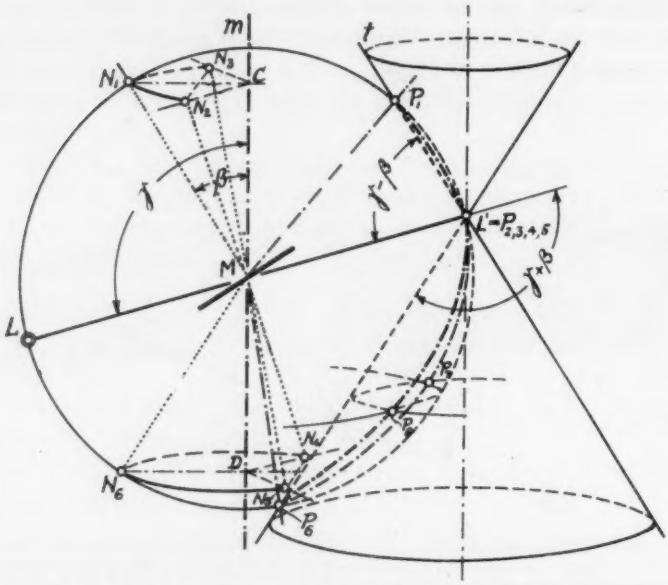
The trace P of the reflected light beam p on the spherical screen will be the line of intersection of the sphere with the t-cone, which is a cone similar to the n-cone transferred parallel with itself, with its vertex transposed in the pole L′ opposite to the L point.

To a pure rotation of the mirror about a stationary axis of rotation corresponds a circular N-line. There are conceivable other kinds of constraint which would result in a non-circular N-line. There is nothing in the foregoing reasoning which would restrict its applicability to a circular N-line, i.e., to a circular n-cone and t-cone. Therefore this theorem is valid for any shape of N-line, i.e., for an n-cone and t-cone having any form of directrix.

APPLICATION OF THE THEOREM TO PARTICULAR CASES.

With the aid of the above stated generally applicable theorem the trace of the reflected beam on the spherical screen will be determined for various values of β (attitude of mirror-normal to axis of rotation) and γ (attitude of incident beam to axis of rotation). The Figs. 4–6 show the effect of altering the

FIG. 4.

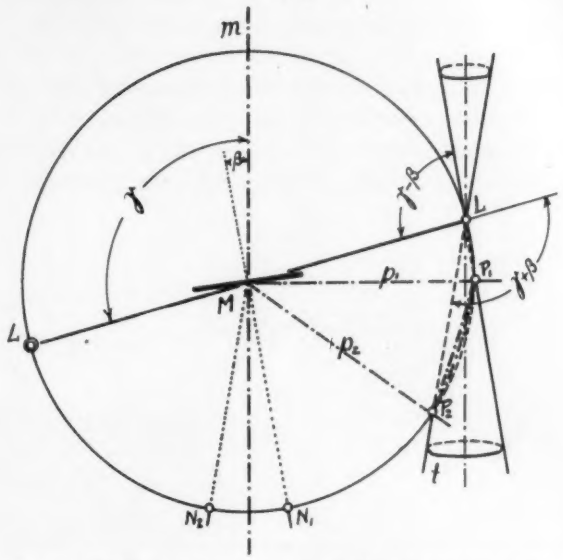


Optical lever with α = variable; $\gamma = 105°$; $\beta = 32°$; the plane $N_2N_3MN_4N_5 \perp LM_i$ for the rotation of the N point within the $\sphericalangle N_2CN_3$ the upper mirror face, for the rotation of N within the $\sphericalangle N_5N_6DN_4N_4$ the lower mirror face is effective; the t-cone intersects the spherical screen in the P points; a plane $\perp$ to m intersects the sphere and the t-cone in circles the common points of which as P_7 and P_8 lie on the intersection of the sphere with the cone; in this case both branches of the t-cone intersect the sphere, hence the resulting, P-curve has two loops which meet in the common L' point corresponding to the normals MN_2, MN_3, MN_4 and MN_5.

β (changing the vertex angle of the n-cone and t-cone) and Figs. 7–10 the effect of altering the γ (changing the position of the L' vertex of the t-cone), as it is briefly explained in the captions. The implications and consequences of the theorem, as illuminated by the examples, will be summarized in the following.

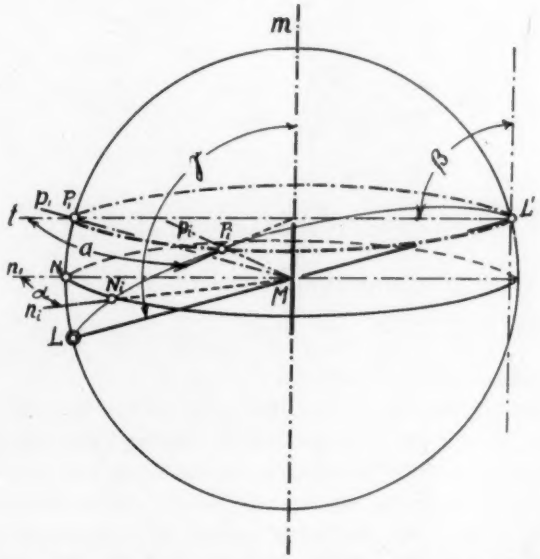
The trace of the reflected beam, being the intersection of two surfaces of the second degree (i.e., a sphere and a cone) is

FIG. 5.



Optical lever with α = variable; $\gamma = 105°$; $\beta = 10°$. In this case only one branch of the t-cone intersects the sphere, therefore the P points form a one-loop curve.

FIG. 6.

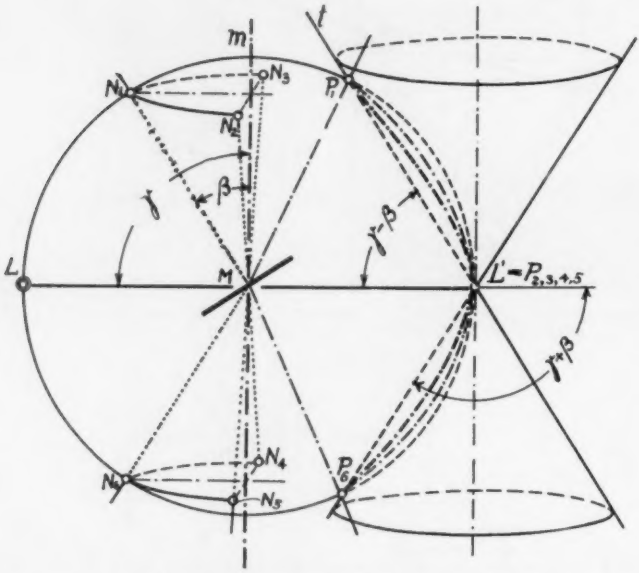


Optical lever with α = variable; $\gamma = 105°$; $\beta = 90°$. The t-cone degenerates into the plane $\perp$ to m passing through L'; the P points lie on a circle; a rotation of the mirror-normal n by angle α rotates the P point by angle a for which $a = 2\alpha$.

in general a spatial curve of the fourth degree, which in singular cases degenerates into a second degree curve, i.e., a circle.

1. If both branches of the t-cone intersect the sphere the result is a two-loop curve, the point of intersection being the L' point. This will occur in cases in which the smallest angle of incidence is an acute angle and the greatest angle of

FIG. 7.



Optical lever with α = variable; $\gamma = 90°$; $\beta = 32°$. The two loops of the P-curve are equal and are completed each by 180° rotation of the mirror.

incidence is an obtuse angle, i.e.,

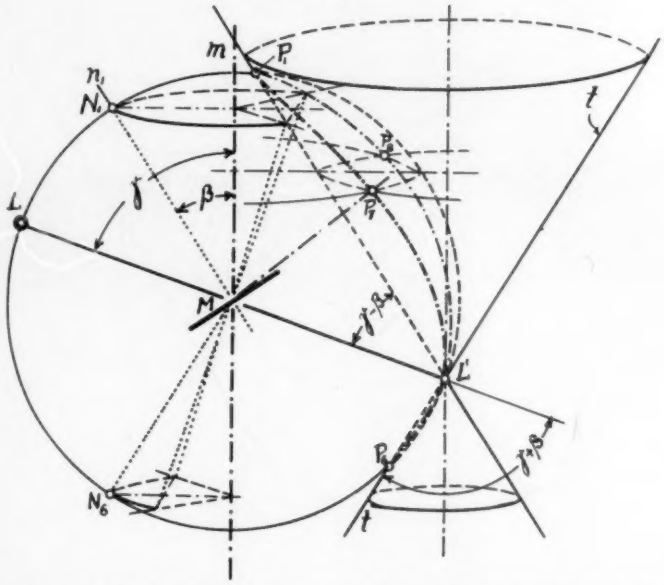
$$(\gamma - \beta) < 90° \qquad \text{and} \qquad (\gamma + \beta) > 90°$$

as it is shown in the examples, Fig. 4, 6, 7, 8.

The two tangents of the curve, drawn to the two branches at the point of intersection will be formed by the two generatrices of the t-cone which are intersected by the plane tangent to the sphere at the L' point. The plane erected perpendicular to LM at the M point will intersect the upper and lower N-circles in points N_2, N_3 and N_4, N_5 respectively

(Fig. 4, 8), which all the four correspond to the point of reflection L'. For the range of the α values lying within the angle $\sphericalangle N_2CN_3$ the upper reflecting surface of the mirror is effective, and the resulting P points will describe the upper loop of the P-curve; for the range of the α values lying within the angle $N_4DN_5 > 180°$ the lower reflecting surface of the mirror is effective and the resulting P points will describe the

FIG. 8.



Optical lever with α = variable; $\gamma = 70°$; $\beta = 32°$. The line of intersection of the t-cone with the sphere is a two-looped P-curve with unequal loops; the construction of the two P_7 and P_8 points is shown by means of intersecting the sphere and the cone with a plane $\perp$ m-axis.

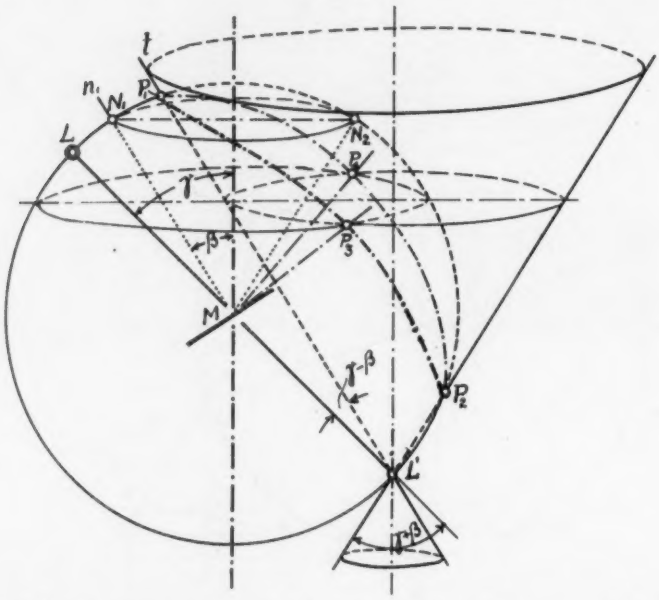
lower loop of the P-curve. In general the two angles of rotation for the upper and lower reflecting surface of the mirror will be unequal, and the two loops of the P-curve will be also unequal.

2. In the particular case when $\gamma = 90°$ (Fig. 7) each of the two loops will be produced by equal rotation of the mirror, hence the two loops will be similar and symmetrically situated with reference to the LL' diagonal as the axis of symmetry.

3. In the particular case when $\beta = 90°$ (Fig. 6) the t-cone degenerates into a plane which is perpendicular to the axis of

rotation, in which plane both branches of the t-cone coincide. The resulting P line will be a circle which is the intersection of the plane erected at L' point, perpendicular to the m-axis of rotation. This circle should still be considered as a two-loop curve having two coincident loops, because during each complete revolution of the mirror the P point will pass around

FIG. 9.



Optical lever with α = variable; $\gamma = 45°$; $\beta = 32°$. The P-curve has one loop; the construction of the two P_3 and P_4 points is shown by means of intersecting the sphere and the cone with a plane $\perp$ m-axis.

the complete P-circle twice, once reflected by one face, then again by the other face of the mirror.

4. If only one branch of the t-cone intersects the sphere the line of intersection will be a one-loop curve which is described by the p-lines radiating from the same reflecting face of the mirror. The criterion for this condition is that the maximum and minimum angles of incidence should be both either acute or obtuse, i.e.:

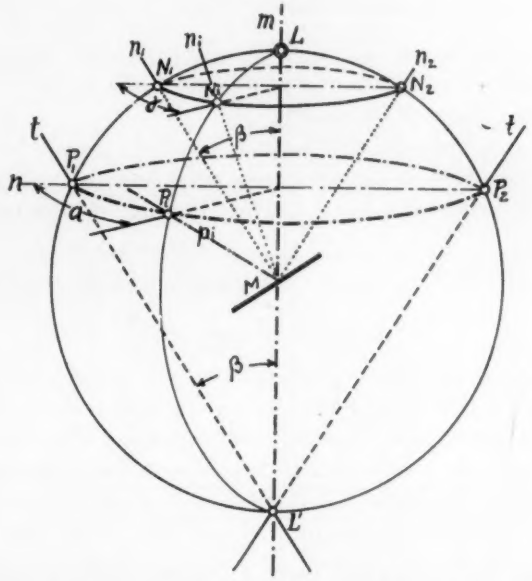
$$\left.\begin{matrix}(\gamma+\beta) > 90° \\ (\gamma-\beta) > 90°\end{matrix}\right\} \text{(Fig. 5)} \qquad \text{or:} \qquad \left.\begin{matrix}(\gamma+\beta) < 90° \\ (\gamma-\beta) < 90°\end{matrix}\right\} \text{(Fig. 9)}$$

5. The particular case (Fig. 10) in which

$$\gamma = 0$$

i.e., the incident beam coincides with the axis of rotation is of interest and importance. In this case the maximum and minimum angles of incidence are equal, $\beta + \gamma = \beta - \gamma = \beta$. For every chosen β value the P points will describe circles in

FIG. 10.



Optical lever with α = variable; $\gamma = 0°$; $\beta = 32°$. The resulting P-curve is a circle, being the intersection of the sphere with the co-axial l-cone; a rotation of the mirror normal by angle α rotates the P-point by angle a, for which $a = \alpha$.

planes perpendicular to the m-axis, resulting in coaxial, circular p-cones. Thus for constant β values the trace of the reflected beam will lie on "latitude"-circles perpendicular to the m-axis, and for constant α, varying β-values the trace of the reflected beam will lie on "longitude" or meridian circles having a common diagonal in the m-axis.

EFFECT OF DEVIATIONS FROM THE ASSUMED CONDITIONS.

The foregoing analysis was based on the essential condition that the point of incidence M (i.e., the intersection of l and n)

lies on the axis of rotation m. Due to misadjustment, or to design necessities deviations from this condition may occur, insofar that

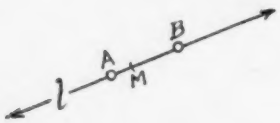
1. l and m are coplanar, but the intersection of the mirror-plane with the axis of rotation does not coincide with the point of intersection of the l and m lines; or,
2. l and m are non-coplanar.

The effect of this condition is that

(a) The point M will not be stationary in space but will wander along the incident beam l to each value of α corresponding a different M point;

(b) The n-lines do not form a conical surface but a ruled surface formed by a family of straight lines of varying directions intersecting the l-line at the varying M points;

FIG. 11.



Motion of the M point (intersection of l with the mirror) along the incident beam, if M does not lie on the axis of rotation. In cases where only one face of the mirror is effective the M will wander between two extreme points A and B; in cases where both faces of the mirror are effective the M point will wander from A to the left to infinity and from B to the right to infinity.

(c) The p-lines do not form a conical surface, but another ruled surface formed by a family of straight lines of varying directions intersecting the l-line at the varying M points;

(d) Interpreting P as the image of L with respect to n as the axis of symmetry, the locus of P points will not lie on a sphere.

In arrangements in which only one face of the mirror is effective the wandering of the M point on the l incident beam will take place between two points, say between A and B in Fig. 11, hence the "ruled" surfaces for n and p will be conoid surfaces, approximating to a cone, and the mean position of the M point can serve as a substitute vertex for such conoids with a fair degree of approximation. In arrange-

ments in which both faces of the mirror are effective the wandering of the M point on the incident beam will take place for one mirror face from A in the direction to the left to infinity, and for the other mirror face from B in the direction to the right to infinity. An approximation to a cone will be admissible only for the positions of the point in the neighborhood of the A and B points. This latter arrangement is the case with the polygonal mirrors used in some oscilloscopes and other physical instruments, in which large deviations from the n and p cone are avoided by the arrangement that each of the several mirror faces is effective only in a small range of the mirror rotation.

The arrangement according to Fig. 10 in which the incident beam l coincides with the m-axis of rotation is the easiest to adjust in this respect and least liable to get out of adjustment, and accidental deviations from strict coaxiality will have the least effect on the wandering of the point, hence will introduce the least distortion of the n-cone, p-cone and P-sphere.

NON-SPHERICAL SCREENS.

In the foregoing analysis the screen was considered to be a sphere, which has the advantage that on it the point for any given α, β and γ values can be easily determined by the theorem derived above. In actual optical indicators α and β are made to change in dependence from the two variables the interrelationship of which is sought, while γ is kept constant. (In some instruments the γ is variable and the β is kept constant.)

To a series of constant α values and variable β values will correspond a series of P_x-curves defining a series of p_x-cones; to a series of constant β values and variable α values will correspond a series of P_y-curves defining a series of p_y-cones. The series of P_x and P_y curves represent a spherical coördinata network in which the indications of the optical lever have to be evaluated.

A spherical screen is, however, unsuitable for actual use, because it cannot be developed into a plane surface. For actual screens only such surfaces are suitable which possess this latter property, i.e., plane, cylinder and cone. Evidently, the coördinata network on these surfaces will be formed by

the lines of intersection of the screen surface with the p_x cones (which shall be called x-lines) and with the p_y cones (which shall be called y-lines).

In general both the x-lines and y-lines will be not readily determinable curves, and in their totality represent a curvilinear coördinata system, requiring the redrawing of the diagrams into a polar or orthogonal coördinata system before they can be evaluated.

The question arises whether any arrangement of an optical lever comprising a plane, cylindrical or conical screen is possible which would provide for varying values of α and β, or α and γ a true polar, or orthogonal coördinata system.

Evidently the line of intersection of a conical p-surface having a fourth degree spherical curve as directrix, with a plane, a cylinder or a cone cannot be either a circle (curve of second degree) or a straight line (curve of the first degree). Therefore our investigation can be restricted to such particular arrangement of the optical lever which result in a p-cone being a circular cone or a plane (i.e., cone with 180° vertex angle). There are two such arrangements:

(A) α = variable, $\beta = 90°$, γ = variable, Fig. 6, (this arrangement necessitates the use of a second mirror for altering the γ);

(B) α = variable, β = variable, $\gamma = 0$, Fig. 10, (one single mirror, having two degrees of freedom of rotation is used in this case).

The p_x-cones (corresponding to constant α-values) will be meridional planes having a common line of intersection in the m-axis; the p_y-cones (corresponding to constant γ-values in case A, and to constant β-values in case B) will be circular cones coaxial with the m-axis. Both these arrangements provide:

1. With a plane screen perpendicular to the m-axis: a polar coördinate system;

2. With a circular conical screen coaxial with the m-axis: a polar coördinate system after the cone had been developed into a plane;

3. With a circular cylindrical screen coaxial with the m-axis: an orthogonal coördinate system after the cylinder had been developed into a plane.

In case *A* (Fig. 6) an α-degree revolution of the mirror produces a 2α degree rotation of the light spot on the screen, and the effective length of the light beam lever is equal: distance from the γ-mirror to the α-mirror, plus distance from the α-mirror to the screen.

In case *B* (Fig. 10) an α-degree revolution of the mirror produces an α-degree revolution of the light spot on the screen, and the effective length of the light beam lever is the distance from the mirror to the screen.

CONVERGENT LIGHT BEAM.

In the foregoing treatment it was tacitly assumed that the light beam is parallel. In actual instruments convergent light beam is used in virtue of its capability of giving a sharper, more intensive light spot on the screen. The convergency of the light beam is obtained by a lens system adjacent to the light source, or by using a parabolic (or in approximation spherical) mirror, or both. The theorem and analysis will be then applicable to the central ray of such a light beam. The requirement arises, however, to keep the light beam on the screen in focus in order to obtain a small, sharp light spot. This involves keeping the total length of the light-beam, from source to screen, constant, which condition could be satisfied only with a spherical screen. With cylindrical or plane screens only an approximation to this condition is attainable by restricting the range of motion of the reflected beam to the values in the vicinity of the perpendicular to the screen. Using cylindrical screen, this condition is satisfied in the arrangement *A* by using γ values within a range of slightly more and less than 90°, and in the arrangement *B* by using β values within a range of slightly more and less than 45°.

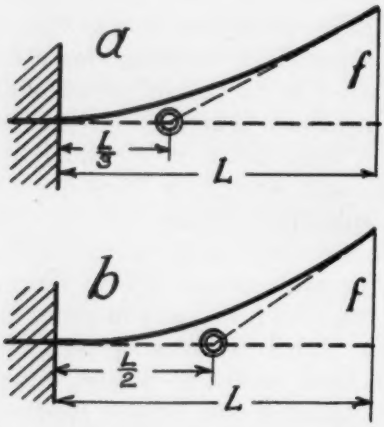
MIRROR SUPPORT.

In view of the smallness of the mirror-rotation it is of the utmost importance that the support shall definitely determine the axis of rotation, and that it should be free from friction and backlash. According to the sensitivity and strength requirements of the various applications several types of mirror-

support are used, such as: single conical pivot, a pair of conical pivots, unifilar and bifilar suspension, knife-edge bearing, elastic rod in torsion and elastic beam in bending. The position of the axis of rotation is clearly defined with all these supports, except the last-mentioned one.

The elastic beam type support possesses the advantages of simple and robust construction, easy repair and interchangeability, freedom from backlash and friction and resistance against unintended motions (such as compression in

FIG. 12.



Virtual axis of rotation with elastic beam mirror-support. (a) With elastic strip of uniform cross-section; (b) with elastic beam of uniform strength.

longitudinal direction, or rotation about its longitudinal axis). Therefore its geometrical features will be briefly discussed.

In Fig. 12 it is assumed that the mirror is fixed to one end of a leaf spring the other end of which is rigidly clamped. The displacement of the mirror-end of the spring produces a rotation by an angle which is—at small displacements—directly proportional to the displacement and inversely proportional to the radius of rotation. Evidently the virtual axis of rotation will lie at the intersection of the tangent drawn to the free end of the spring with the tangent drawn to the clamped end of the spring, and will therefore be determined by the shape of the elastic curve. Two cases will be considered:

(*a*) *Beam of Uniform Cross-Section* (Fig. 12*a*).—From the equation of the elastic curve:

$$y = P\left(\frac{Lx^2}{2} - \frac{x^3}{6}\right),$$

the slope of the free end of the spring can be expressed:

$$\tan \alpha = \frac{3}{2}\frac{f}{L},$$

i.e., the virtual axis of rotation is situated at $\frac{L}{3}$ distance from the point of clamping.

(*b*) *Beam of Uniform Strength* (Fig. 12*b*).—The elastic curve is in this case a circle, or, in first approximation, a quadratic parabola; the slope of the free end can be expressed:

$$\tan \alpha = 2\frac{f}{L},$$

i.e., the virtual axis of rotation is situated at $\frac{L}{2}$ distance from the point of clamping.

CRITIQUE OF ACTUAL OPTICAL INDICATORS.

In the light of the above developed principles a number of representative types of indicators will be critically examined.

1. *Mirror Galvanometer* (Fig. 13).—In this case α = variable, $\beta = 90°$, γ = constant. This instrument is a "-meter" because only one variable is measured along a scale. A number of arrangements are possible:

(*a*) If $\gamma \neq 90°$ and the screen is a cylinder of R radius, coaxial with m, then the trace of the light spot will be a straight line on the developed cylinder, and its excursion from the meridian plane of the light source will be

$$a = 2R\alpha.$$

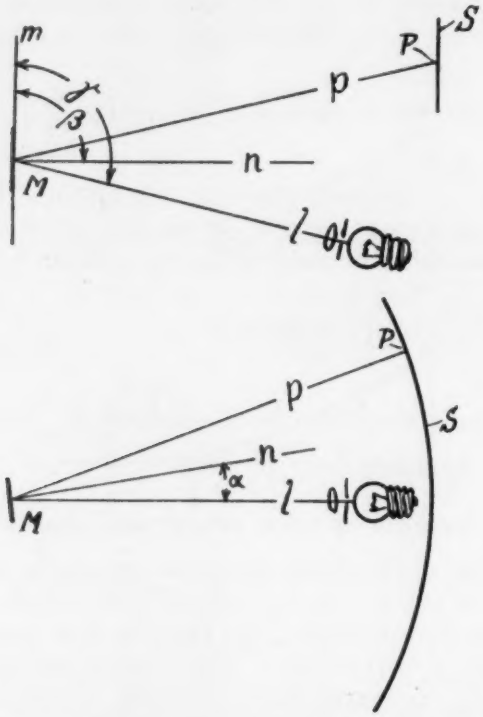
(*b*) If $\gamma \neq 90°$ then on a plane screen perpendicular to m the trace of the light spot will be a circle concentric with m,

and its excursion from the meridian plane of the light source will be

$$a = 2R\alpha.$$

(*c*) If $\gamma \neq 90°$ and the screen is a plane parallel with m then the trace of the light spot will be a branch of hyperbola.

FIG. 13.



Optical arrangement of a galvanometer. As illustrated $\gamma > 90°$ and the screen is cylindrical. In some galvanometers $\gamma = 90°$ and a plane screen is used.

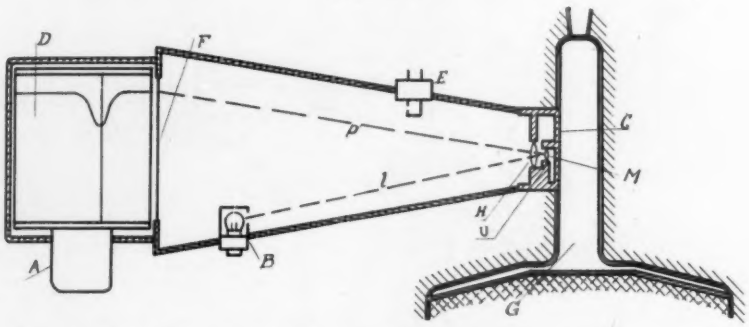
(*d*) If $\gamma = 90°$ then the p-cone will degenerate into a plane perpendicular to m, and the light spot will describe a straight line on a cylindrical screen coaxial with m, and also on a plane screen parallel with m. The excursion of the light point on the plane screen will be

$$S = R \tan 2\alpha.$$

2. *Optical Engine Indicator of the N.A.C.A.* (Fig. 14).—The mirror has one degree of freedom of rotation about the fixed point U which is not coincident with the point of impingement of the incident beam. This deviation is necessitated by design considerations and involves a variation in the effective length of the incident and reflected beam as the mirror is oscillated. The motion of the pressure-responsive diaphragm is however so small that this deviation is negligible.

Apart from this deviation this arrangement can be characterized by: α = variable; $\beta = 90°$; $\gamma = 90°$. The re-

FIG. 14.



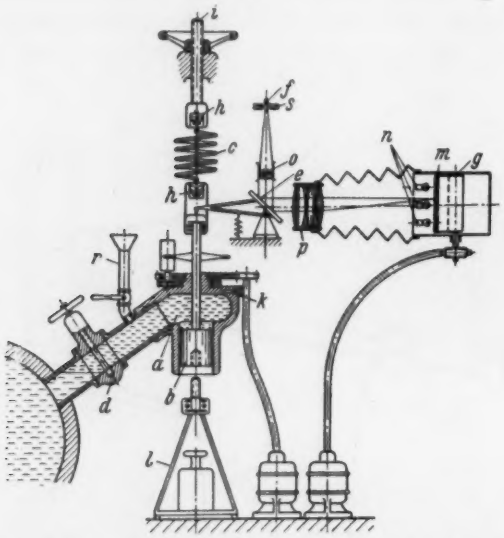
Optical engine indicator of the N.A.C.A. The mirror M is oscillated about the axis U by the diaphragm C actuated by the pressures in the combustion chamber G of the engine. B = light source; l = incident beam; p = reflected beam; D = film drum rotated by the A electric motor. The lens H brings the beam to a focus on the surface of the film drum D. The slit F in the drum casing reduces the dimension of the light spot reaching the film. The spark-gap E placed in series with the spark plug of the engine serves for marking the instant of ignition on the rotating film drum.

sulting p-cone degenerates into a plane, which is the plane of the drawing. The diagram is formed on a rotating film drum. The intersection of the film drum with the p-cone will give the lines of constant drum angle φ, i.e., in this case constant time. The intersection of a p-beam with the rotating drum will describe a line of constant α-angle, in this case a line of constant pressure. If the p-cone (i.e., the plane of the drawing) is parallel with the rotational axis of the drum a truly orthogonal coördinata system will be obtained. (If the p-plane is not parallel to the axis of the drum the resulting lines of constant abscissa will be sine-curves.) For sharpest light spot the drum axis should lie in the p-plane; for least deviation from sharp focus the median position of the reflected beam should

be perpendicular to the drum axis. These principles have been incorporated in the design as illustrated. The indicator of Thoma (Fig. 15) is similar in principle to the N.A.C.A. indicator having a mirror of one degree freedom and a rotating film drum.

A shortcoming of optical indicators with film drum is that

FIG. 15.

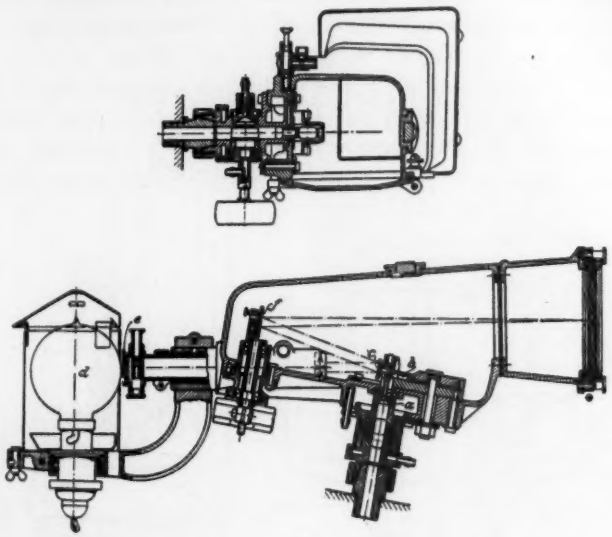


Optical indicator of Thoma for measuring the pressure fluctuations in water conduits. The pressure in space *a* displaces the piston *b* against the force of spring *c* the ends of which are located in universal knife-edge bearings *n*. The piston-spring assembly can be raised and lowered by means of handwheel *i*. The displacements of the piston rod change the angular position about an axis ⊥ to the plane of the drawing of mirror *e* upon which a light beam impinges from source *f* through aperture *s* and condenser lens *o*; the reflected beam is focussed by means of lens *p* onto the film drum *g*. The three lamps *n* mark through the three apertures *m* three reference lines of constant ordinata on the film drum. The piston *b* is kept in rotation by means of an electric motor and gear train *k* in order to eliminate friction in the axial direction. Space *a* above the piston can be filled with oil through the funnel *r*. The gate-valve *d* serves for shutting off the piston space from the water conduit, when no measurement is desired. The deflection of the light beam can be calibrated in terms of piston force with the aid of the weights *l*.

no visual inspection of the trace of the light spot is possible, without photographing it on the film.

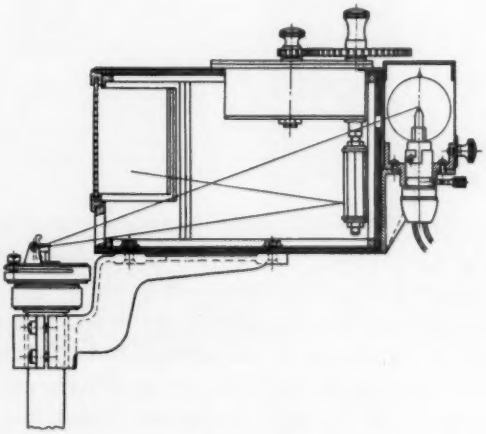
3. *Optical Indicator by Burstall* (Fig. 16).—In this instrument two mirrors are incorporated, *c* for the measurement of pressure and *f* for the measurement of piston travel, each of which has a one degree freedom of rotation about mutually perpendicular axes. The *c*-mirror can be characterized: α = variable; $\beta = 90°$; $\gamma > 90°$ (the light source is actually

FIG. 16.



Optical engine indicator by Burstall. The pressure in the engine cylinder acts upon the piston *a* which deflects the cantilever spring *b* to the end of which the mirror *c* is fastened. The oscillations of the engine piston are communicated, at a reduced scale, to the mirror *f*. The light source *d* is below the plane of the drawing, hence the trace on the mirror *f* of the beam reflected by mirror *c* will not be a straight line.

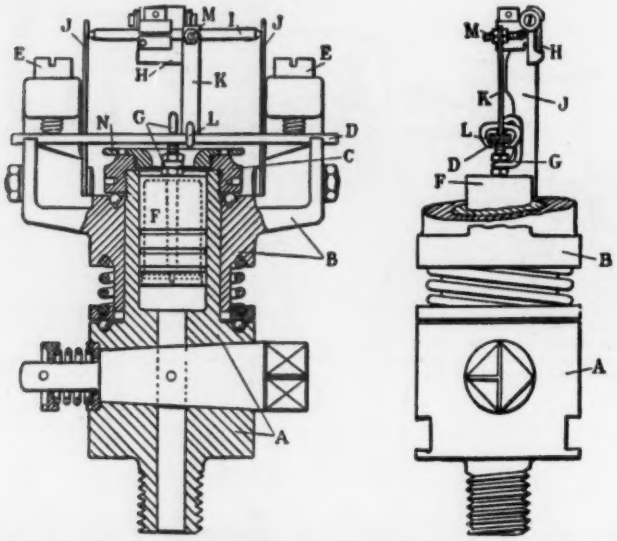
FIG. 17.



Optical engine indicator by Midgley. The beam reflected by the pressure-mirror intersects the axis of the polygonal mirror. The pressure-time diagram is formed on a cylindrical screen.

below the plane of the drawing for design reasons). The M point is not coincident with the axis of rotation of the c-mirror but owing to the small range of α the effect of this is not serious. The resulting p-cone will have a vertex angle $160°$-γ, and its intersection with the f mirror will be hyperbola. For the f-mirror: α = variable, $\beta = 90°$, γ = variable. If the incident light beam lies in the plane of the drawing the beam

FIG. 18.

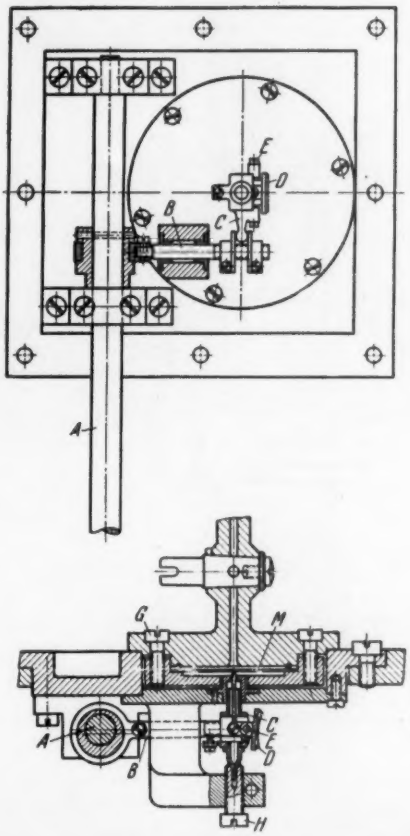


Optical engine indicator by Hopkinson. The pressure forces acting on piston F deflect the beam spring D. The deflections are converted, by means of the connecting rod K and lever M into angular displacements of the mirror H. The mirror is fastened to the pivot I located, in cone and socket bearings, in the two upright pillars J. The whole piston-spring-mirror assembly can be rotated about the axis of the piston. Thus the mirror H has a two-degree freedom of rotation. The incident beam is not coincident with either axis of rotation, hence the resulting diagram will not be recorded in orthogonal coördinates.

reflected by the c mirror will also lie in the plane of the drawing, and its intersection with the f mirror will lie in the rotational axis of the f mirror. The case would be then identical to the Fig. 6 and, with a cylindrical screen coaxial with the axis of the f-mirror an orthogonal coördinata system would be obtained. In this instrument the screen is not cylindrical, nor is it parallel with the rotiatonal axis of the mirror f. Owing to these deviations from the basic principles the coördinata system of the screen will be not strictly

orthogonal but will be composed of two systems of curved lines. The curvature of the coördinata lines is however

FIG. 19.



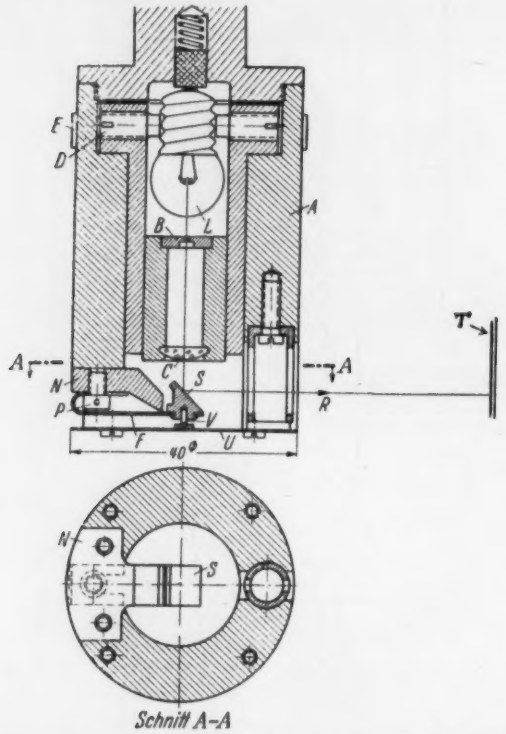
Optical engine indicator of the Societe Genevoise. The engine pressures act on diaphragm *M* the displacements of which are communicated, by means of the pushrod situated in the plane of the paper, to the mirror *D*, oscillating it about axis *E* which is perpendicular to the diaphragm pushrod. The travel of the engine piston is produced, on a miniature scale, by the eccentric *A* and connecting rod *B*, which is communicated to the pivot *C*, causing thereby an oscillation of the mirror about the diaphragm pushrod as the axis of rotation. Thus the mirror *D* has a two-degree freedom of rotation about mutually perpendicular axes. The incident beam is not coincident with either axis of rotation, hence the resulting diagram will be recorded in non-orthogonal coördinates.

minimized by restricting the rotation of the mirrors (especially that of the *c*-mirror) to a small angle.

4. *Optical Indicator by Midgley* (Fig. 17).—In this instrument two mirrors are incorporated, a pressure-mirror and a

polygonal, time-mirror, each of which has a one-degree freedom of rotation about mutually perpendicular axes. For the pressure-mirror: α = variable, $\beta = 90°$, $\gamma = 90°$. The reflected light beam will rotate in the plane of the drawing.

FIG. 20.



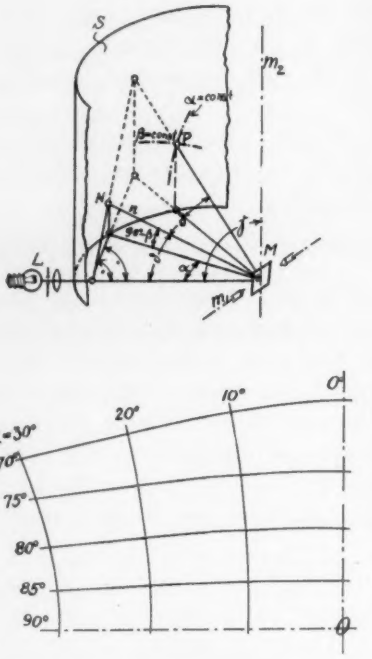
Optical indicator by DeJuhasz for magnifying and recording small motions. The small motion which is to be magnified and recorded is communicated to the diaphragm U and through the pin V to the mirror S. This latter is fastened on the end of leaf-spring F mounted on the block N, the end of which forms a knife-edge about which the oscillations of the mirror take place. L = light source; B = aperture plate; C = lens; D = centering screws for the light source; E = conductor ring for supplying current to the lamp. The elements are assembled in the Bakelite barrel A which is rotated bodily in proportion to time, crank-angle, piston-stroke, or any other variable, as a function of which the small motion is to be recorded. The reflected beam R describes on a cylindrical screen (not shown) the magnified motion, in a true orthogonal coördinate system.

The point of incidence does not lie in the rotational axis of the mirror, but in view of the small range of rotation the effect is negligible. The characteristics of the polygonal mirror have been discussed earlier in this paper.

5. *Optical Indicator by Hopkinson* (Fig. 18).—In this

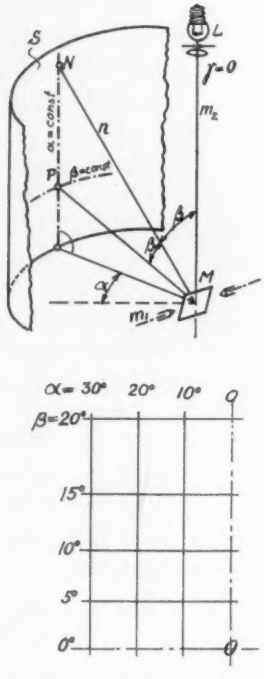
instrument is incorporated a single mirror H with two degrees of freedom of rotation about two mutually perpendicular axes. The mirror is fastened to the horizontal I axis, which is carried in the supports J, which in turn are fastened to the frame B

FIG. 21*a*.



α = variable; β = variable; $\gamma \neq 0°$. On a cylindrical screen the resulting α = const. and β = constant lines are curves (Fig. 21*b*).

FIG. 21*b*.



α = variable; β = variable; $\gamma = 0$. On a cylindrical screen the resulting α = const. and β = const. lines are straight lines, perpendicular to one another (Fig. 21*d*).

Paths of light beam with optical levers having a two-degree freedom of rotation.

rotatably arranged on the outside of the vertical indicator cylinder. The point of incidence, which is somewhere in the middle of the H mirror, does not lie on either of the axes, though the incident beam can be made to intersect the vertical axis of rotation. As the rotation about both axes is only of small amount, these deviations have no serious effect.

The optical lever can be characterized: α = variable, β = variable, γ = constant. The case corresponds to Fig. 4. Truly orthogonal or polar representation cannot be attained on either plane, or cylindrical, or conical screen. The lines of constant α and of constant β are curves (Figs. 21*a*, *b*). The deviation is minimized by restricting the motion of the mirror to small α and β values.

6. *Optical Indicator of the Societe Genevoise* (Fig. 19).—Is similar in its optical principle to the Hopkinson indicator, having one single mirror D with two degrees of freedom of rotation.

7. *Optical Indicator by DeJuhasz* (The Pennsylvania State College), (Fig. 20) is based on the arrangement schematically illustrated in Fig. 10 characterized by

$$\alpha = \text{variable}, \qquad \beta = \text{variable}, \qquad \gamma = 0.$$

In this case, with a cylindrical screen, coaxial with the axis of rotation of the mirror, a truly orthogonal coördinata system will be obtained (Figs. 21*c*, *d*); and with a plane screen perpendicular to the axis of rotation of the mirror, and also with a conical screen coaxial with the axis of rotation of the mirror, a truly polar coördinata system will result. With a plane screen parallel with the stationary axis of rotation the lines of constant α will be parallel straight lines, the lines of constant β will be hyperbolas.

THE FIRST ORRERIES IN AMERICA.

BY

HARROLD E. GILLINGHAM.

When attempting to ascertain from the average dictionary the meaning of the word *Orrery*, one is puzzled by the different descriptions of this eighteenth century instrument. One of the simplest definitions of it is "a piece of mechanism devised to represent the motions of the planets about the sun by means of clockwork." [1] This same authority gives the meaning of a *Planetarium* as an Orrery, or a model representing the planetary system. Dr. Gunther describes an Orrery as a "machine for representing by wheelwork the various motions of the heavenly bodies" and further states that it differs from a Planetarium in that it exhibits the diurnal as well as the annual motions of the earth, the revolutions of our moon, and sometimes the rotations of the sun and of certain planets on their axes.[2]

The "Encyclopædia Britannica" [3] describes it as "An astronomical instrument—consisting of an apparatus which illustrates the motions of the solar system by means of the revolutions of balls moved by wheelwork—invented, or at least constructed, by Graham" and named for, or after, Charles Boyle (1676–1731), the fourth Earl of Orrery.

While the invention of the orrery is attributed to George Graham (1675–1751), a celebrated instrument maker in the early part of the eighteenth century, his first instrument had only the earth, moon and sun displayed in their rotations, and as John Rowley had made such a piece, adding other planets, some have given Rowley credit for the first invention, which is believed in error.[4]

[1] "The Shorter Oxford English Dictionary," 1932.

[2] R. T. Gunther, *Early Science in Oxford*, vol. II, 267.

[3] 13th Edition, 20–329.

[4] J. T. Desaguiliers, in "A Course of Elemental Philosophy," 2nd edition, London, 1745, states "George Graham was the first person in England to make an Orrery . . . about 25 or 30 years ago." Which would place Graham's production about 1715 to 1720.

Thomas Wright, of Fleet street, London, "Mathematical Instrum^t. Maker to His Majesty George y^e II^d", made an Orrery in 1731 for the king, which is in Christ Church College, Oxford. Two years later he made another for the Royal Observatory at Richmond which cost £1,500. Joseph Harris in "Description and Use of Globes and the Orrery," 1763, states that Wright likewise made Orreries for Mr. Watt's Academy in Tower street; for his Majesty at Kensington; for the Royal Naval Academy at Portsmouth; one for the Duke of Argyle and several others "for Noblemen and Gentlemen." [5]

Just who made the first instrument of this character which came to America in 1732 the records fail to reveal, though circumstances point to Wright. The Hollis family had been generous benefactors to Harvard College. Thomas Hollis (1659–1730), son of a wealthy London merchant, and ardent Baptist, began a series of gifts as early as 1719, and five years later contributed £426 toward establishing a Professorship in Mathematics.[6] It was his nephew, Thomas, the son of Nathaniel Hollis, who on July 20, 1732, wrote to Coll. Hutchinson, Treasurer of Harvard, as follows:

> "Inclosed I send you a bill of lading for two cases No. T.H.1.2. Shipping Union, John Homans; the one contains a sphere; ye other a new invented engine or macheen called an orrrery, showing the dayly & annual motion of ye sun, earth & moon. I have also delivered ye Captain a small shagreen case with a double microscope." [7]

This was the *first* Orrery to come to America and was mentioned in *The Boston Weekly News-Letter* of September 14, 1732, as follows:

> "Cambridge, Septem. 9. We have received from Mr. Hollis, Nephew of the late pious and most generous Thomas Hollis Esq; of London; a fresh Confirmation of his Generosity and Regard to the College, in a very rich Addition to the Philosophical Apparatus; consisting of a curious Microscope, a large and exquisite Armillary Sphere,

[5] *Early Science at Oxford*, II, 270.

[6] *Harvard Graduates Magazine*, March 1895, p. 342.

[7] Harvard College Collection.

and a very costly Orrery, an Instrument, that this, or any other Part of America, as far as we can learn, has never before been favoured with."

Harvardians were justified in being proud of their acquisition. The fact that such a highly scientific instrument had been received in Cambridge was of sufficient importance for the *Pennsylvania Gazette*, No. 201, October 5, 1732, to reprint a duplication of this notice for Philadelphia readers. But alas! *Harvard Hall*, a building 97 feet long by 42 feet wide, four stories high, built in 1672, was destroyed by fire on January 25, 1764, and the library of over 5,000 volumes, all their scientific apparatus and the Hollis instruments were "All Destroyed," as stated in a Broadside in the present Harvard Library. Other instruments likewise lost were "a brass Quadrant of 2 feet radius, carrying a Telescope of a greater length; which formerly belonged to the celebrated Dr. Halley." [8]

This disastrous fire soon brought friends of Harvard College to its assistance. In 1764 Hon. James Bowdoin (1727–1790), Governor of Massachusetts, presented the College with an Orrery, listed as costing £85.5.0,[9] and in a list of Philosophical Apparatus, made three years later, another Orrery is mentioned as having been made by Benjamin Martin, of London, described as "A large complete orrery. . . . A set of wheelwork in a brass box with weights etc. to keep ye orrery in motion independent of ye winch," which, with its case, was then valued at £90.15.6.[10] About two years after Harvard College received their first Orrery, the importance of which was fully appreciated by scholars in other cities of the

[8] Edmund Halley, 1656–1742, an English astronomer of great note.

[9] Josiah Quincy, "The History of Harvard University," vol. II, 484.

[10] Benjamin Martin was working in London from 1757 to 1771. In the latter period he published a pamphlet "The Description and use of an Orrery of a new construction, to which is subjoined a mathematical theory for calculating the Wheel-work to the greatest degree of exactness." Likewise giving prices for six types of Orreries. The sixth "with all the additional machinery" was priced at £157.10.0. (*Early Science in Oxford*, by R. T. Gunther, vol. II, 271–2.) "A Catalogue of Philosophical, Optical and Mathematical Instruments Made and Sold by Benjamin Martin, At his Shop, the Sign of Hadley's Quadrant and Visual-Glasses, near Crane-Court, in Fleet-Street" was reproduced in the April, 1938 issue of *Sands, Clays and Minerals*, vol. III, No. 3, a copy of which is in The Franklin Institute Library.

colonies, *The New York Gazette*, No. 454, July 8, 1734, printed a 6½ inch column notice on their front page describing the wonders thereof; closing with:

> "And therefore it is hoped that in time not only each Province, but each principal Town in these parts will think it as necessary to have an Orrery as a publick Town Clock, the one gives the Time of the Day and Night, the other presents to our View the wonderful VVorks of the Diety."

Photograph of a mezzotint engraving by William Pether (1738–1821) executed about 1768, after an engraving by Joseph Wright (1734–1797) of Derby, England. In 1766 Wright exhibited this painting at the Society of Artists in London described as "A philosopher giving that lecture on the orrery in which a lamp is put in place of the sun." Painting now in the Derby Corporation Art Gallery. The man at lower right is said to be Joseph Wright the painter. *Courtesy Adler Planetarium, Chicago.*

As other English instrument makers were likewise making Orreries, it is reasonable to suppose their products soon reached our colonial students. The *Pennsylvania Gazette*, No. 1147, for December 6, 1750, had this notice:

> "ON Monday, the 10th of this Inst. at three *a* Clock in the Afternoon, will begin, at the Library, A Course of

> Experimental Philosophy, consisting of six Parts, viz. Physics, Pneumatics, Hydrostatics, Optics, Geography, and Astronomy. The astronomical Part will be explain'd and illustrated by a curious large ORRERY. Each subscriber is to pay two Pistoles, one at the first Lecture, and the other at the End of the Course; and to receive a gratis Ticket for one Lady to attend the whole Course. Sylabusses, containing the Particulars of each Lecture, to be had gratis at the Post-Office. Subscriptions are taken by David James Dove, at Mr. Duche's, in Chestnut-street." [11]

Apropos of David James Dove's printed notice, Edward Shippen Sr. of Philadelphia, wrote his son Joseph Shippen—then a student at the College of New Jersey [at Newark], several letters from May to September 1751, regarding Dove's intention of going to Newark, and later to New York, to lecture on the Orrery. Dove apparently never went, but finally Lewis Evans did go with the Orrery and other apparatus giving lectures thereon, after he had received six weeks' instruction from Benjamin Franklin; who—as Shippen states—"we account one of our Solomons." Some of these letters are well worth quoting in order to clear the question of Dove's having lectured in Newark or New York.

> "Philad[a]. 19th June 1751. "I am just come In from the Academy & M[r]. Dove Tells me that his apparatus is packt up ready to you this week: it would have gone before had it not been for Lewis Evans who would not finish his Affairs before."
>
> "A Philadelphie 9th May 1751. Mons[r]. Dove me dit hier que Mons[r]. Lewis Evans avait pris beaucoup de peine d'apprendre la Philosophie et qu'il en a fait de grande progrez, et Si l'on ne croye pas, Mons[r] Franklin lui donnerait un Certificate le quel il doit porter avec lui a Nouvelle Yorke a la fin du Courant. J'ay offert a Mons[r] Dove de la Part de Mons[r]. le President Burr Trente Livres (monnoye de cette Province) s'il donnerait Permission a Mons[r] Evans de porter son apparatus a Nouvelle Arche [Newark, N. J.] a fin quil y fasse exhibition de ces Lec-

[11] The maker of Dove's Orrery is unknown at present.

tures, Mais cet Orgueillieux s'en facha & me dit avec Serment, qui'l ne rabuisseroit pas le prix primierment fait."

"Philad[a] June 25[th] 1751 This afternoon I received your Favour of Yesterday and I have been with M[r] Dove and seen his apparatus put up in boxes and Trunks ready to set off with; But he now concludes according to M[r] Burr's desire to goe first to New York."

"Philad[a] the 18th day of July 1751. . . . Lewis Evans is at last gone with his apparatus for New York; I think he went away last Monday and intended to goe through Amboy."

"A regard de Monsieur L. Evans, j'attens avec mi patience d'apprendre de son arrivée á Nouvelle Arche."

"Philadelphia le 31[st] Janvier 1750–1. P.S. Monsieur Dove a dessein en tete d'envoyer son Orrery & sont Apparatus a Nouvelle York le Courant d'Avril, ou, ai Mois de Mai, & Monsieur Le Professeur Voudroit bien passer par Nouvelle Arche se l'on vent de lui donner trente ou quarant Pistoles mais peutetre quil receivre Moins."

"Fevrier 5, 1750–1 . . . Le Curateurs de l'Academie ont persuade Monsieur Dove de rester dans cette ville & lui donnent £150 l'an enseigner la Langue angloise & Mons[r] Baron le Professeur de Philosophie doit traverser le Continent avec L'Orrery & L'Apparatus."

"Phila. 11[th] Sept. 1751—I was very glad to hear that M[r] Evans exceeds our expectations; to be sure he took a vast deal of pains to Qualify himself for the Business; and he had the daily Instruction for 6 Weeks before he Sett off, of M[r] Franklin whom we account one of our Solomons. M[r] Evans' discouragement at New York was (as Neddy informs me under the Rose) owing to M[r] Hill, who it seems made it his Business all the time he was in that city to represent M[r] Evans as a person quite unequal to the Task he undertook—which between you and I Jo. was unkind both in respect to Dove; as well as to "the Gentlemen of his (Hill's) acquaintance in York. It is true he and Dove are not on the best Terms in the world; but these things are no excuse for such behaviour." [12]

[12] "Shippen Family Correspondence," vol. 1, pp. 99–131. The Historical Society of Pennsylvania Collection. Copied for the writer by Mr. Charles B. Montgomery, to whom gratitude is hereby expressed.

Dove remained in Philadelphia and became a teacher of Languages at the Academy, or College of Philadelphia. In 1761 he was chosen Master of English at the Union School of Germantown (later the Germantown Academy), but having been dismissed two years later, he opened an independent school in Videll's Alley, in Philadelphia.

Confirming Edward Shippen's letter of July 18th, the following notice appeared in *The New-York Gazette Revived in the Weekly Post-Boy*, of July 29, 1751:

> "A COURSE OF NATURAL PHILOSOPHY AND MECHANICS. To be exhibited, at the House of the Rev. Mr. Ebenezer Pemberton in the Broad-way, in New York. A Course of Natural Philosophy, and Mechanics, illustrated by Experiments, By Lewis Evans. This Course consists of 13 Lectures, treating of the nature of this World and its Parts. The Solar System is explained by a most curious Orrery, which represents the annual and dirunal Motions of all the Planets Primary and secundary, the Causes of Day and Night, Winter and Summer Eclipses of the Sun and Moon, etc.
>
> "The Mathematical Terms, Figures and Proportions, necessary for the Understanding of these Lectures, are explained for the Sake of the Ladies and Gentlemen unskill'd in the Mathematics." [13]

Unfortunately we are not advised where Lewis Evans procured his Orrery used in these lectures, though we may assume it is the same used by David James Dove in Philadelphia.

It might not be out of place to mention here those Mathematical Instrument Makers of England who were capable of making Orreries, Planetariums (as some called them) and other such scientific apparatus. No doubt some of their productions had reached our colonies by the middle of the eighteenth century.

GEORGE ADAMS, "at Tycho Brahe's Head in Fleet Street, London" c. 1750, made a "Grand Orrery" now in the Sedgwick Museum at Cambridge, England. It is mounted on a 12-sided box-base, 3 feet 6 inches across, on a table 4 feet

[13] "The Arts and Crafts in New York 1726–1776," The New York Historical Society, 1938.

square. The figures of the Zodiacal signs are painted in each of the 12 sides of the base.[14] Adams was the author of "A Treatise on the Construction and Use of Celestial and Terrestrial Globes," 2nd edition, 1769.[15]

B. COLE and B. COLE & SON, "At the Orrery, Fleet street, London" (were successors to Thomas Wright, Q.V.), 1750–1782, made an Orrery for Queen's College, Oxford.

GEORGE GRAHAM, 1675–1751, heretofore referred to. Made an Orrery for Prince Eugene of Savoy (1663–1736) who is credited with having won the battle of Blenheim (August 13, 1704) with the Duke of Marlborough. He later became Governor of The Netherlands.

THOMAS HEATH, 1714–1774, of The Strand, London. Made a Planetarium now in Le Conservatoire National des Arts et Métiers, Paris, and one in All Souls College, Oxford.

W. & S. JONES, 1790–1815, at 30 Holborn, London. A nineteenth century Orrery of theirs is in the Peabody Museum, Salem, Massachusetts.

BENJAMIN MARTIN, 1751–1771 (q.v.). An Orrery of his making in the Science Museum of London and one in Harvard College, Cambridge.

EDWARD NAIRNE, of 20 Cornhill, opposite the Royal Exchange, London, c. 1761–1806. A maker of all kinds of Mathematical and Astronomical Instruments. The Franklin Institute now has a "Way-Wiser" made by Nairne, presented by the writer.

JOHN ROWLEY, of Fleet street, London, worked from 1690 to 1716. Orreries and Planetariums of his making are in Christ Church College, Oxford.[16]

THOMAS WRIGHT, working 1718–1751, of Fleet street, London (succeeded by B. Cole, q.v.). An Orrery of his making is in the Lewis Evans Collection at Oxford, one in Christ Church College at Oxford, and one at the Royal Observatory at Richmond, c. 1733.[17]

J. T. DESAGUILIERS. Author of "A Course of Experimental Philosophy," previously mentioned, who said, on page

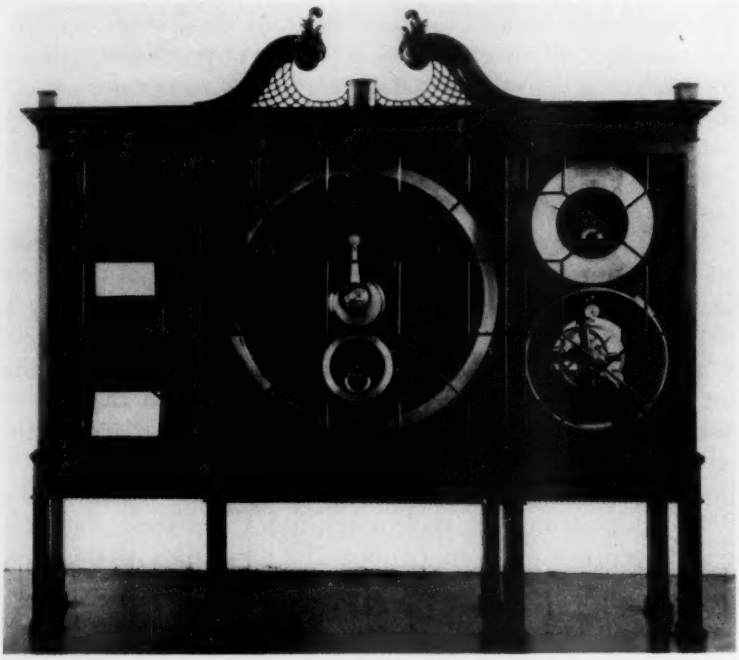
[14] *Early Science in Oxford*, vol. II, 191.

[15] Copy in the writer's collection.

[16] *Early Science in Oxford*, vol. II.

[17] *Early Science in Oxford.*

448, "I have here subjoined a short Description of my Planetarium; an Instrument which I made lately," indicating that he too had made Orreries. This instrument was described as being 3 feet in diameter, six inches high, with twelve vertical panels. No doubt these twelve "verticle panels" each contained a sign of the Zodiac.



The Rittenhouse orrery, owned by the University of Pennsylvania, now in the Museum of The Franklin Institute.

What is considered the outstanding Orrery in this country —at least to Philadelphians—is that made by David Rittenhouse for the University of Pennsylvania, and at present exhibited in The Franklin Institute. This was undoubtedly "made with the man's whole heart and soul in it." About 1769 Rittenhouse made an Orrery for the College of New Jersey—now Princeton University—which at the present time is lost entirely to students. At the same time he produced another such instrument for the College of Philadelphia which, fortunately for those interested, is still in complete working

order. Parnell Gibbs, a hand-fire-engine maker and John Folwell, cabinetmaker and carver, made the handsome mahogany case for the Orrery, which cost £65.[18] The case is 8½ feet long, 7 feet 8 inches high and 17 inches deep, standing on eight legs. The center section, four feet square, contains the earth, the sun, the planets Mercury, Venus, Mars, Jupiter and Saturn; all known at that time. The right hand section, 27 inches wide, shows the movements of the Moon, together with the year, month and day of eclipses; given for a period of 5,000 years before and 5,000 years after the year in which this marvelous instrument was made. The left hand section —now vacant—was originally intended to show Jupiter and Saturn on a larger scale, but was never completed by Rittenhouse.[19]

Much has already been written of this Rittenhouse Orrery and as it was so entirely different from all English-made instruments of the kind, it has attracted—in this country at least—much interest. The *Pennsylvania Journal* for March 28, 1771, had a long notice regarding the instrument, stating that "The Members of Assembly having viewed the Orrery, constructed by Mr. David Rittenhouse, a native of this Province, and being of opinion, that it greatly exceeds all others, hitherto invented, in demonstrating the true situation of the Celestial Bodies, their magnitudes, motions, distances, periods, eclipses and order, upon the principles of the Newtonian System,

"Resolved, That the Sum of Three Hundred Pounds be given to Mr. Rittenhouse, as a testimony of the high sense which this House entertains of his Mathematical Genius and Mechanical Abilities, in constructing the said Orrery. . . . That this curious Machine deserves the commendations which the Assembly have bestowed upon it, will never be doubted by those who are capable of forming any judgement concerning it, and will attend to the following particulars."

Then follows a long description of the Orrery and its workings, closing with "that it will not vary above one degree from the truth in 304 years, but this is only about the twentieth part of the accuracy of our Pennsylvania Orrery;

[18] The bill for same is in the Smith Papers, at the University of Pennsylvania.

[19] *Pennsylvania Magazine*, July 1932, by James Stokley.

for it will not vary a degree from the truth in less than six thousand years, if the present order of Nature subsists." [20]

What is believed to be a little known letter from Dr. William Smith of the "College" to David Rittenhouse, dated February 21, 1771, is as follows:

> "The little Paper which you have drawn up for Mr. Jacobs, giving some Account of your Orrery, is not only just as far as it goes, but if your Modesty had permitted, you might have said infinitely more in its Favor. As to its being a copy, or in any Way on the Plan, of any other Orrery ever yet constructed, no Person who has any knowledge of Astronomy, or had read Descriptions of Orreries made elsewhere, will venture to assert it. With Respect to what you say of its Advantages to Youth in giving them proper Ideas of the true System of Astronomy, I not only agree with you, but am sure, from what I have already experienced, that by the Help of it, I could give young Students a better Idea and Knowledge of Astronomy by it in one Month than I could perhaps in Six months without it; owing to its peculiar Construction in giving the true Inclinations of the Plains of the Orbits, & Dimensions of our System. . . ." [21]

In the same collection is another unsigned statement regarding the David Rittenhouse Orrery—said to be in the handwriting of David—which is worth quoting in part:

> "The maker can boldly affirm, that he has not copied the general construction, nor the particular disposition, of any of its essential parts, from any Orrery or description whatever, neither has he made use of any Number he found in books, for one single wheel, but was at the pains of getting them by calculations himself, having never met with any that were exact enough for his purpose."

All of which exemplifies David Rittenhouse's particularly advanced education in astronomical science and his genius in producing an Orrery so entirely different in construction from

[20] "Arts and Crafts in Philadelphia," Alfred Coxe Prime, vol. 1, 264–266.

[21] "Jacobs Family Papers," vol. II, 435. Historical Society of Pennsylvania. Courtesy of Mr. Charles B. Montgomery.

any of the European instruments made, or described in publications to which he undoubtedly had access through local libraries.

At this time the scientific world was much interested in the study of astronomy and as Orreries were desired by students of the subject, it was natural that other American craftsmen who were capable of producing such instruments should have turned their attention thereto. About 1786 Joseph Pope (1748–1826),[22] a mathematician, watch-maker and mechanical genius of Boston, conceived the idea of making an Orrery for Harvard College. That institution, lacking in funds, appealed to the public authorities for permission to hold a lottery, the proceeds of which were to compensate Pope for his apparatus. The net proceeds of this lottery were £521.17.9, £450.3s. being paid to Pope and the balance of £71.14.9 being paid to the College treasury. The Orrery was delivered to the College in December 1788. Curiously enough Joseph Pope, the maker of the instrument, was born in Hollis street, Boston; so named for Harvard's early English patron.

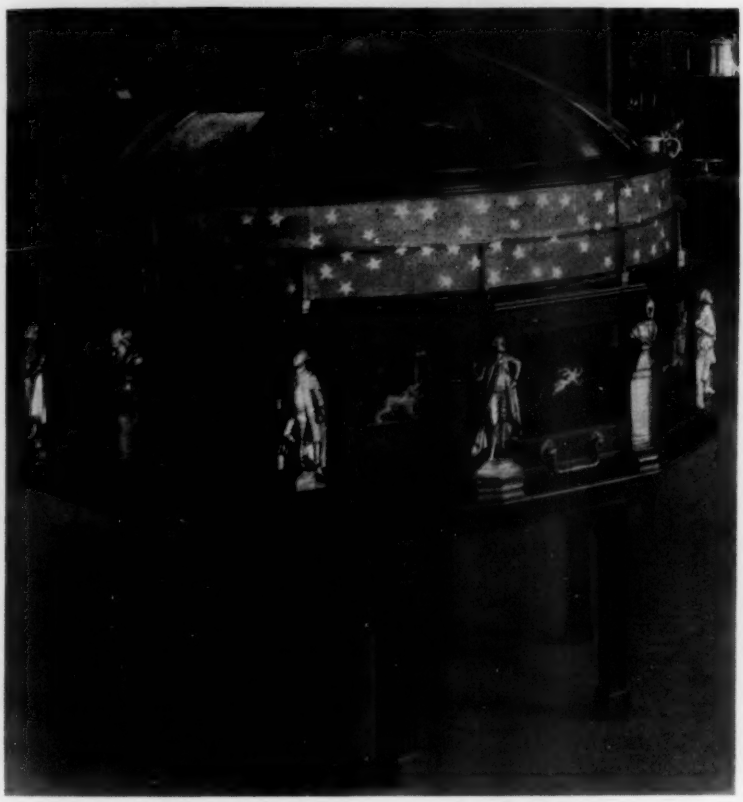
Remembering what David Rittenhouse wrote: "that he had not copied the general construction, nor the particular disposition, of any of its essential parts, from any Orrery or description whatever," one is led to believe such was not the case with Joseph Pope. His Orrery does not appear to be original in design, but is more of a copy—or at least quite similar in design to that made by George Adams, c. 1750, now in the Sedgwick Museum, Cambridge, England; and that made by B. Cole & Son about the same time which is in Queen's College, Oxford. Heath & Wing's Orrery in All Souls College, Oxford, is likewise quite similar to Pope's.[23]

The Pope Orrery, now preserved at the Harvard College Observatory, Cambridge, Massachusetts, rests on a hexagonal mahogany table made in the Chippendale style, five feet in diameter and with six reeded legs. Upon this rests the Orrery itself, $5\frac{1}{4}$ feet in diameter and twelve-sided. On each of the

[22] Justin Winsor, in "Memorial History of Boston," 1881, vol. IV, 500, gives his birth as 1750.

[23] "Early Science in Oxford," vol. II, and "Early Science in Cambridge," by R. T. Gunther.

twelve glass panels is painted one of the signs of the Zodiac. At each corner of the periphery are cast brass figures, said to have been first carved in wood patterns by Simeon Skillen and cast by Paul Revere. These figures are repeated four times around the Orrery. One is of Governor James Bowdoin

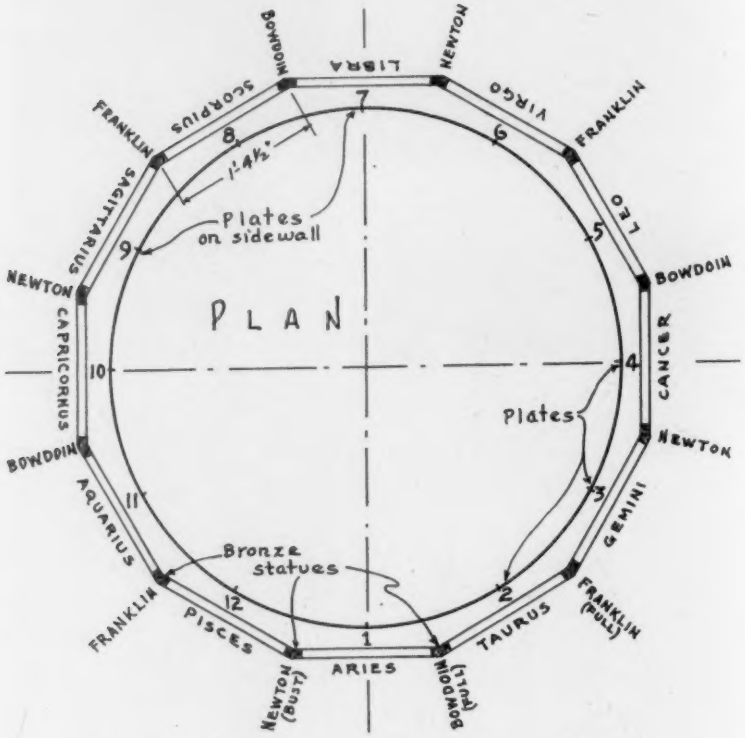


Orrery made by James Pope, c. 1786–1788. Harvard College Observatory.

(1727–1790), from whom Bowdoin College in Maine is named. Another is of Sir Isaac Newton (1642–1727), with astronomical signs depicted on the base.[24]

[24] In addition to his astronomical and philosophical knowledge, Newton was Master of the Royal Mint in 1699 and it is claimed the reformation of English coinage was his work. He was a member of the French Academy of Sciences and of the Royal Society of London.

The third figure is that of Benjamin Franklin (1706–1790), with a lightning rod at the right, which reminds us of the inscription on the Franklin Medals, "Eripuit coelo fulmen sceptrum que tyrannis." The figures of Bowdoin and Franklin are full length, about sixteen inches high, while that of Newton is a bust on a pedestal.



Measured drawing of the Pope orrery made by R. Newton Mayall, Boston.

Above the periphery is a metal band about ten inches high, on the outside of which are depicted stars, and the inside has in colors the several signs of the Zodiac and of the stars in the region. Above all is a cleverly designed glass dome to allow a clear vision of the mechanism of the Orrery. Metal plates are attached to the floor of the instrument, inscribed by the figures 1, 2, 3, etc. as follows:

1, Sun's diurnal rotations on its axis, etc.; 2, Mercury, with its annual period around the sun, rotation, etc.; 3, Venus; 4, the Earth; 5, the Moon; 6, Mars; 7, Jupiter; 8, Jupiter's

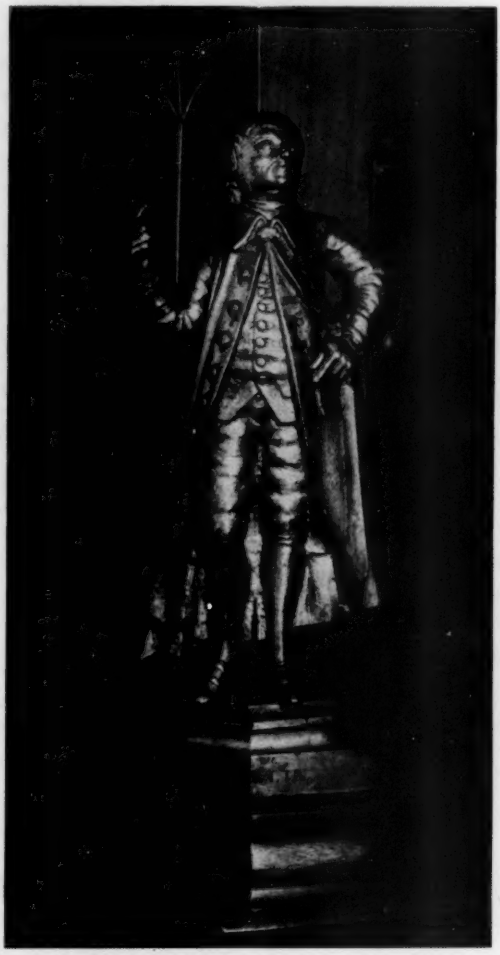


Figure of Benjamin Franklin showing lightning rod. Pope orrery, Harvard College Observatory.

moons (4); 9, Saturn; 10, Saturn's five moons; 11, Table, showing the sun and planets, with their hourly motions, etc., and 12, a Table, similar to No. 11, giving the diameter in

English miles, diameter as seen from the sun, proportion of diameters, of bulk, of gravity and of density.

This item regarding the Pope Orrery, taken from *A History of Simon Willard, Inventor and Clockmaker*, Boston, 1911, pp. 26–27, is worthy of note:

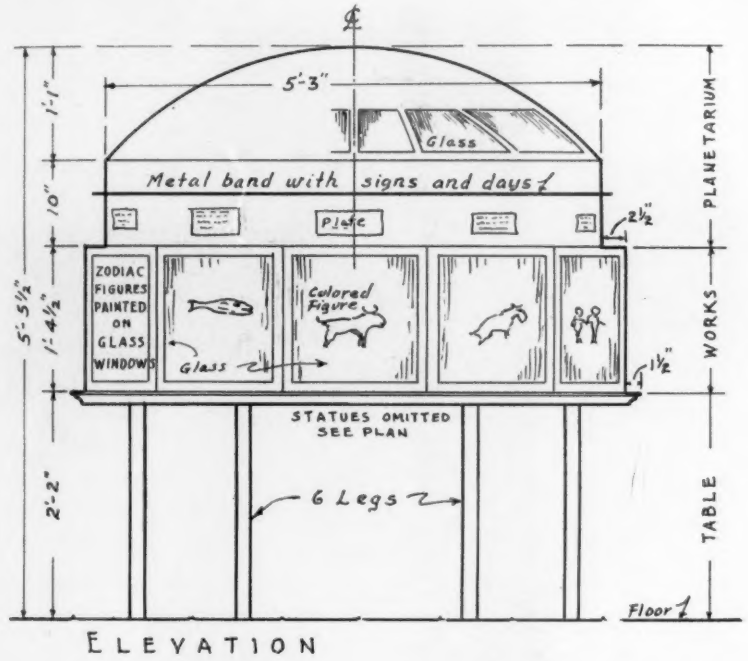
> "Simon Willard was quite prominently connected with Harvard College; he had sole charge of the clocks in the College for many years. His feat in perfecting the great Orrery of Mr. Joseph Pope, who after having devoted several months to the detection of an error in construction, was compelled to abandon it as a failure, was a fine piece of mechanical skill. This particular Orrery would work all right up to a certain point when suddenly the whole solar system would give a tremendous jump, to the despair of its inventor. Many skilfull mechanics were called in to remedy the defect, but all gave it up, and finally Simon Willard was appealed to, with the offer of untold sums if he could make it run smoothly. Simon Willard looked it over carefully, took out his drill, drilled a hole in a certain place, put in a rivet (he always called it a ribbet in telling the story), and the Orrery worked to perfection; the whole operation not taking over an hour. The authorities were delighted. 'Now, Mr. Willard,' they said, 'how much do we owe you?' 'Oh,' said Willard, 'about nine pence will do I guess.'"

Here the writer wishes to express the greatest appreciation to Mr. R. Newton Mayall, of Boston, for his scale drawing and complete description of the Pope Orrery at the Harvard College Observatory, which at the time of the Tercentenary of Harvard in 1936 was in fairly good working order, but has since then been unworkable.

What is believed to have been the fourth known American-made Orrery was produced by Aaron Willard, Jr., a Clockmaker, of Washington street, Boston, in 1821. This is now preserved in the Chester County Historical Society at West Chester, Pennsylvania. The authenticity of this piece, as well as its original ownership, has been proven beyond doubt.

The minutes of the West Chester Academy show it was ordered on "April 3, 1821 for the sum of $60.00 delivered in

Philadelphia in good condition" from Aaron Willard, Jr., who has subscribed on the dial plate the following information: "Made by A. Willard, Jr. Boston" above and "For the West Chester Academy" below. The plate of the Orrery is twelve inches in diameter and the entire apparatus is $9\frac{1}{2}$ inches high, all fitting into a mahogany box 14 inches square and ten



Measured drawing of the Pope orrery made by R. Newton Mayall, Boston.

inches deep. The apparatus has two separate attachments, one celestial, the other terrestrial, worked by a crank handle extending from under the zodiacal plate.

When the West Chester Academy became the State Normal School in 1869 the Orrery came into the possession of Washington Townsend, one of the trustees of the former school, whose daughters presented it to the Chester County Historical Society for preservation. And just why the Academy authorities went to Boston for such an instrument to use in their scientific studies is not explained. David Rittenhouse

had passed away and Philadelphia and New York instrument makers seem to have confined their productions to nautical instruments, rather than to such scientific instruments as might have been produced by those excellent New England clock-makers. The Willards of Roxbury and Boston, Massachusetts, had specialized in clocks for years. Simon Willard,

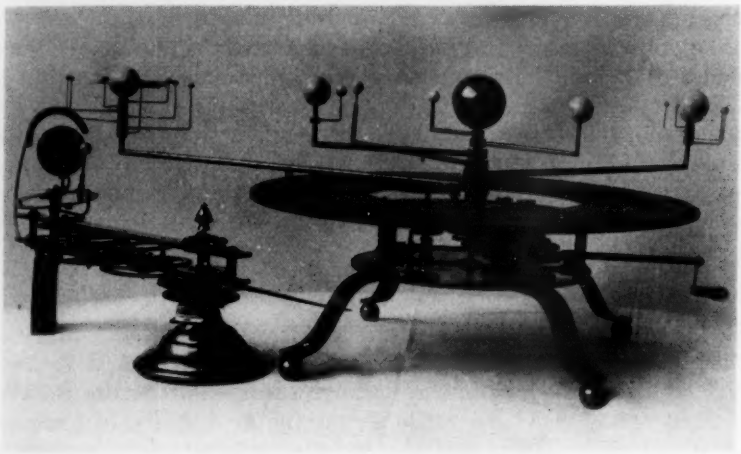
Orrery made by Aaron Willard, Jr., in 1821 for the West Chester Academy. Now in possession of the Chester County Historical Society.

the uncle of Aaron, Jr., had advertised "Time pieces for Astronomical purposes price 70 Dollars";[25] and as Aaron, Jr. (1783–1863), had been apprenticed to his father, likewise a clock-maker, it is reasonable to suppose that in his studies as well as during his apprenticeship to his father, he had absorbed sufficient information on astronomical matters from English

[25] N. Hudson Moore, "The Old Clock Book," New York, 1911.

publications to conceive the idea of the Orrery now at West Chester.[26]

Orreries of the general design of Willard's are not uncommon in American collections. The Franklin Institute have on display several which follow the general design. The writer has one purchased in London in 1930, attributed to the first quarter of the nineteenth century, made by Newton, Chancery Lane. It has only the celestial appliances. And several similar ones are in various European museums. Let us hope this record of early American-made Orreries may bring forth information of other such instruments perhaps



Working parts of Willard orrery. Now in possession of the Chester County Historical Society.

hidden away in closets and out-of-the-way places in our first scientific societies and colleges. Today the public is given more scientific instruction from the several Planetariums installed in Philadelphia, New York and Chicago, which cover the astronomical information given to earlier students by the use of Orreries. As Benjamin Franklin is reputed to have said, "The world is daily increasing in experimental knowledge, and let no man flatter the age with pretending that we have arrived at a perfection of our discoveries." [27]

[26] William Ball, Jr., "Another American Orrery," in Magazine *Antiques*, October 1938.

[27] George Wharton Pepper's Address at Chicago, April 14, 1939, THE JOURNAL OF THE FRANKLIN INSTITUTE, July 1939.

A Procedure for the Identification of Commonly Used Waxes in Admixture.—SAMUEL ZWEIG and ABRAHAM TAUB, Columbia University, N. Y., presented a paper on this subject at the recent meeting of the American Chemical Society. The increasing world consumption of waxes and their extensive utilization in commercial polishes and other wax containing products has brought to the fore the need for a definite procedure of analysis of waxes in admixture, a problem which hitherto has proved decidedly complex because of the qualitative similarity and natural variations of these substances. The method proposed in the paper utilizes a correlation of pertinent physical and chemical constants with a quantitative separation of waxes into groups of homologous compounds and a study of their properties. The study is limited to the common waxes: spermaceti, carnauba, candelilla, beeswax, montan, and ozokerite. Certain allied substances such as cetyl alcohol, stearic acid, and rosin are included to indicate where they might interfere in the analysis. The precipitation temperatures of the waxes in *n*-butyl alcohol and *n*-heptane are proposed as criteria for the detection of carnauba and ozokerite in a mixture of waxes. The quantitative separation involves the isolation of an ethanol-soluble fraction, high and low molecular weight fatty acids, hydrocarbons, and high and low molecular weight fatty alcohols.

R. H. O.

Large Portable Elevator Used to Clean Ceilings of Library of Congress.—(*Packing and Shipping*, Vol. 66, No. 7.) A large portable, collapsible "Jack-in-the-Box" elevator, built by the Revolvator Company, has been put in service by the Library of Congress in Washington, D.C., to facilitate the cleaning of high ceilings, skylights and chandeliers, and the storing of books on high shelves. The elevator is equipped with a platform that can be raised from low height of 6½ feet to a maximum height of 35 feet. The elevator is constructed of structural steel, and the apparatus is powered by a ¾ h.p. electric motor, which, when the switch is turned on by a man standing on the platform, will raise or lower the platform at the rate of 10 feet a minute, through the arrangement of a Link-Belt Silverlink roller chain. A steel ladder is attached to each of the five sections of the elevator platform to climb up with tools or anything else that is needed, without having to lower the platform. The Revolvator Company, the manufacturers, say that this elevator is one of the largest portable elevators of this type ever constructed.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

INTERFEROMETER FOR MEASURING DIMENSIONAL CHANGES IN RUBBER.

A method for measuring small dimensional changes by the use of an interferometer was developed by Fizeau and Abbe many years ago. Light of known wave length transverses an air gap between two quartz plates separated by the material being studied, and interference occurs between the beams reflected from the surfaces of the plates. Changes in the dimensions of the specimens cause corresponding changes in the air gap, and a displacement of the interference fringes occurs. In this manner it is possible to measure the displacement in terms of the wave length of the light employed.

The application of this method of measurement to soft rubber is described in a paper by L. A. Wood, Norman Bekkedahl, and C. G. Peters which will be published in the November *Journal of Research* (RP1253). The relatively easy deformation of the rubber gives rise to problems which do not occur in the application of the interference method to such rigid substances as metals, glass, and ceramic materials, to which it has been previously applied. The paper discusses the apparatus used and the technique employed in the measurement of dimensional changes in rubber and gives consideration to its limitations as well as to its advantages in comparison with other methods. Particular emphasis is placed on measurements at temperatures as low as that of liquid air for the determination of the expansivity at different temperatures and of the dimensional changes involved in transitions between different forms of rubber and of the temperatures at which the transitions occur.

The lower limit of temperature was set only by the refrigerating liquid. With unvulcanized rubber, excessive plastic flow made measurements impossible at temperatures

* Communicated by the Director.

above about 40° C.; with vulcanized rubber, however, no upper temperature limit set by plastic flow was observed in a series of observations which extended as high as 100° C.

The method requires continuous observation, but as compared with alternative methods of measuring small dimensional changes it possesses advantages arising from its high sensitivity, the small size of the specimens required, ease of obtaining temperature equilibrium, absence of a confining liquid, and the simplicity of the calculations.

IMPROVEMENTS IN RADIO SONDE.

Recently, a significant advance has taken place in weather forecasting, based on the routine collection of upper-air data to heights of $15\frac{1}{2}$ miles by means of radio soundings. This method developed at the Bureau has supplanted the use of airplanes carrying calibrated recording instruments for securing upper-air data.

The radio-sonde system as described in Technical News Bulletin 263 (March, 1939), employs an instrument carried aloft on a small unmanned balloon, and ground station receiving and recording equipment. The balloon instrument, or radio sonde, comprises elements for measuring barometric pressure, air temperature, and humidity; a radio transmitter and power supply; and means for inpressing on the radio transmitter modulating frequencies which have predetermined relationships to the values of the factors measured. At the ground station, the frequencies of the received signals are measured and recorded automatically, thereby providing a plot of temperature and humidity against pressure.

A year's experimental use of the system during 1938–1939 at 12 stations by the Navy Department, Weather Bureau, and Coast Guard provided data which exceeded both in regularity and accuracy the observations previously obtained by the airplane soundings. During the present fiscal year, the service is being expanded to include 30 land and 5 shipboard stations. One of the features of the experience with the radio-sonde system has been the excellent operation obtained by the shipboard stations.

An improved form of the radio sonde has been introduced at 3 of the stations and is to be used soon at 6 more stations. The essential improvement consists of the incorporation of a new device for measuring relative humidity, which utilizes the phenomemon of variation in conductivity of a hygroscopic salt when exposed to different relative humidities. In its operation as a resistor the value of which varies with relative humidity, it parallels the temperature element used in the radio sonde which functions as a resistor varying in accordance with the ambient temperature. The two measuring resistors and two fixed reference resistors are switched into the modulating oscillator of the radio sonde by a switch responding to changes in the ambient pressure. The modulating frequency is thereby controlled to provide measurements of pressure, temperature, and humidity.

IMPROVED ELECTRICAL HYGROMETER.

The wet and dry bulb psychrometer and hair-type hygrometer have long been used for determining the moisture content or relative humidity of air. There are, however, many possible applications for which these types of instruments have not been suitable. This is especially the case in measuring upper-air humidities by means of the radio sonde. Such an instrument, ascending rapidly, encounters very large and abrupt humidity changes which occur too rapidly for the psychrometer or hair hygrometer to follow completely. Furthermore, these types of humidity indicators do not lend themsleves readily to graphical recording or registering of humidity remote from the point of measurement, they are comparatively large, and do not function well at very low temperatures.

A new type of electric hygrometer has recently been developed by Francis W. Dunmore of the Bureau's Radio Section, and is described in the *Journal of Reasearch* for December (RP1265). It has proved superior to other types for radio-sonde use because its rapid response and ability to function at low temperatures. It may also be used for making and recording humidity reading when the humidity unit is

remote from the point of indication. As it is comparatively small it may be used for measuring humidities in confined spaces.

Although the device seems simple, it has required two years to bring it to the present stage of development. It now gives results accurate to within 2 or 3 percent.

The hygrometer consists of two fine palladium wires spirally wound about 1/64-inch apart, 20 turns per inch, on a thin-wall aluminum tube which has a thin coating of polystyrene resin. This resin is one of the best known water-resistant substances as well as an excellent electrical insulator. The wound unit is then covered with a very thin film of partially hydrolyzed polyvinyl acetate with the addition of a small amount of lithium chloride. The latter takes up water very rapidly. With such a device the electrical resistance of the film between the two spiral coils is dependent upon the humidity of the air in contact with the film. The variations in resistance may change the audio note which the radio sonde transmits or may be made to operate a direct-reading ohmmeter with the resistance scale marked in terms of percent relative humidity.

There are definite reasons for each step in the development of the unit as given above. The thin-wall aluminum tube enables the unit to assume quickly the temperature of the air, the relative humidity of which it is to register; otherwise the indications will not be correct. The polystyrene film forms a surface of high electrical resistance which will not absorb water upon which to wind the two palladium wire coils. Absorbed moisture would cause a lag in the indications of the device. The paladium wire coils remain fixed in their electrical properties, whereas units wound with wire of other metal (except platinum and gold) continue to vary from week to week because of some film forming on the surface of the wire. The thin polyvinyl acetate film serves as the electrical conductive medium. It has the property of taking on or giving off water very readily. It acts as a binder for the lithium chloride which is the active material. This is one of the most hygroscopic salts. By controlling the amount of lithium chloride in the film, hygrometer units may be made with different degrees of sensitivity. By con-

necting several such units in parallel, each with suitable resistors in series, humidities from 10 to 100 per cent. may be measured.

ALUMINUM ION AND HYDROGEN ION IN PAPERS.

It was recently reported in *J. Research NBS*, **22**, 553 (May, 1939), RP1205, that a simple procedure for the determination of pH of papers, involving cold aqueous extraction, gives values which are as closely related to the amounts of alum used in manufacture and to the stabilities of the papers as are those obtained with methods employing hot extraction. The former, by virtue of its simplicity, eliminates the factors which apparently account for the rather poor reproducibility among laboratories using the standard method. Thus, the basis for preferring the procedure involving cold extraction was a practical one.

Further work has shown, however, that there is also a fundamental basis for preferring the method of cold extraction. Heating of the paper-water mixtures was found to increase greatly the hydrolysis of the aluminum salts in the papers, thereby producing as much as 3 to 4 times the amount of acid originally found in the cold extract. Such large amounts of acid obscure the effects of smaller amounts of other acids which may result from cooking or bleaching operations, or which may be present owing to polluted atmosphere, any of which are known to cause deterioration of papers.

The heating operation has a further serious drawback. Partial hydrolysis of the aluminum salts in papers with the liberation of harmful acid may take place when papers are stored or shipped under warm, humid conditions, or when the drying or other manufacturing processes were faulty. This acid cannot be detected by the method of hot extraction, since the heating process causes more or less complete hydrolysis, irrespective of any partial hydrolysis which may already have occurred. The method of cold extraction, on the other hand, gives pH values corresponding to the hydrolysis equilibrium at room temperature. If the aluminum salt was already partially hydrolyzed by faulty storage or manufac-

turing conditions, the acid thus liberated is measured in the unheated extract.

If the acidity of a paper, as it exists under conditions of use, can be employed as a measure of permanence of paper, and it appears that this is true, then the method of cold extraction gives a much closer measure of the significant pH values of papers than do the more complicated methods now in general use.

The complete report of this study will appear as RP1262 by Herbert F. Launer in the December number of the *Journal of Research*.

EFFECT OF POURING TEMPERATURE ON PROPERTIES OF CAST RED BRASS.

In a paper before the Temperature Symposium of the Institute of Physics at the Hotel Pennsylvania, New York, on the evening of November 2, H. B. Gardener, Research Associate of the Non-Ferrous Ingot Metal Institute at the Bureau described the procedures used in measuring the temperature of red brass during melting and casting. Illustrations were given of the differences in physical properties obtained in castings of this alloy poured at different temperatures.

The Non-Ferrous Ingot Institute has sponsored this investigation since 1930. Technical research has been restricted to a study of effects of pouring temperature and of impurities on the physical properties of the widely-used cast red brass of the nominal composition of 85 per cent. of copper and 5 per cent. each of tin, zinc, and lead.

It was necessary to devise a suitable method for measuring the temperature of the metal while in the furnace and also during pouring. In the earlier phases of the investigation pouring temperatures of 1040° C., 1095° C., 1150° C., 1205° C., and 1260° C. were used, but in the later work the pouring temperatures were restricted to 1065° C., 1150° C., and 1230° C. It was found that the pouring temperature usually had a greater influence on the physical properties of the alloy than had certain intentionally added impurities.

SONIC METHOD FOR STUDYING EFFECT OF FREEZING AND THAWING ON CONCRETE.

Various freezing and thawing tests have been developed in an attempt to find a rapid method for judging the resistance of building materials to weathering over an extended period. How to determine the extent of the deleterious action is one of the principal problems in such tests. Visual inspection and loss in weight have long been used, but they do not tell enough about changes within the specimen. Determination of the change in modulus of elasticity by the static method is considered very useful, but has the disadvantage of being slow and injurious to the specimen.

Recently methods have been developed for measuring certain natural frequencies of a test specimen. By making use of the proportionality between the elastic modulus and the square of the natural frequency of a free-free bar vibrating in the fundamental flexual mode, the modulus of elasticity of the specimen can be determined. In one variation of this method developed by F. B. Hornibrook and now used at the Bureau, the specimen is vibrated at different frequencies until the frequency is found which corresponds to the natural frequency of the vibration of the specimen itself.

The results from this method were compared with strength changes of concrete specimens which had been subjected to freezing and thawing. The percentage decrease in modulus of rupture was found to be nearly equal to that in elastic modulus. The percentage decrease in compressive strength was, in general, considerably smaller.

Instantaneous Fluid-Pressure Recording Instrument.—The oscillographic recording of impulsive or cyclic pressure is a matter of some importance to the engineer, the mechanical engineer being interested in the cyclic variation of pressure in the internal combustion engine and the electrical engineer being interested in the impulsive rises of pressure occurring in tanks and in the arc control chambers of switchgear. S. E. GOODALL and R. B. SMITH in *Engineering*, Vol. 148, No. 3838, describe a recorder of robust construction, having a reasonably small pressure unit and able to respond to rapid rates of change of pressure. The principle employed is that the pressure to be measured produces small capacity changes in a pressure unit by means of a diaphragm being used to form one plate of a condenser. The capacity changes are translated into large current changes in an oscillograph element. The unit to which the pressure is applied is, in effect, a small air condenser which forms one arm of a four arm bridge to which a high frequency voltage is applied. The output of the bridge is a modulated high frequency voltage, the modulation of which is proportional to the change of capacity of the pressure unit for small variations. This signal is amplified and rectified thereby producing unidirectional current proportional to the fluid pressure which operates one element of an oscillograph.

R. H. O.

Refrigerant-Cooled Motor Drives 100 Ton Compressor. (*Electrical Engineering*, Vol. 58, No. 11.) Completion of a hermetically sealed 100 ton 16 cylinder air conditioning compressor unit driven by a 100 horsepower 1,150 r.p.m. refrigerant cooled motor recently was announced by the air conditioning department of the Westinghouse Electric and Manufacturing Company, East Springfield, Mass. The new unit is intended particularly for stores, factories, theaters, and similar applications. Of extremely compact design the unit is said to require only one third the space that would be required by a compressor of conventional design for the same capacity, and to weigh only two thirds as much. It weighs 4,200 pounds and its over all dimensions are: length 90 inches, width 34 inches, and height 36 inches. The single unit type of construction permits of sealed in lubrication, and a reversible oil pump prevents harm when motor phase connections are inadvertently reversed, thereby reversing the direction of rotation. The refrigerant is Freon.

R. H. O.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, DECEMBER 20, 1939.

The regular monthly meeting of The Franklin Institute was called to order at 8:15 o'clock, by Dr. Henry Butler Allen, Secretary and Director.

The minutes of the November meeting were approved as printed in the December issue of the Journal.

The additions to membership since the last report were as follows:

Sustaining	1
Active	16
Associate	33
Student	24
Total	74

In accordance with ARTICLE IV, Section 4, of the By-Laws, the Chairman read the following nominations for Officers and Managers for the term beginning January 1940:

President
(to serve one year)
Philip C. Staples

Vice-Presidents
(to serve one year)
Walton Forstall
W. Chattin Wetherill
S. S. Fels
Richard W. Lloyd

Treasurer
(to serve one year)
Benjamin Franklin

Members of the Board of Managers
(to serve three years)
Irenee DuPont
W. H. Fulweiler
Nathan Hayward
Horace P. Liversidge
Malcolm Lloyd, Jr.
Marshall S. Morgan
Coleman Sellers, 3d
William H. Winterrowd

Announcement was also made of the Christmas lectures under the James Mapes Dodge Foundation which will be held on the afternoons of December 27, 28 and 29. Dr. Carleton John Lynde will be the speaker and his subject will be "Science Experiences with Simple Equipment."

There being no further business the Chairman introduced Professor James K. Finch of the Department of Civil Engineering of Columbia University, New York, who addressed the meeting on: "Man's Battle Against Fire." The speaker reviewed the progress made in fire prevention and outlined modern fire equipment, devoting special attention to modern methods of construction and efforts to

reduce fire hazards. The lecture was illustrated by lantern slides and a moving picture showing tests of new fire resistive wall construction.

After a rising vote of thanks the meeting adjourned.

HENRY BUTLER ALLEN,
Secretary.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 776 readers made use of the facilities during the twenty-five days of November.

RECENT ADDITIONS.

ASTRONOMY.

WOODBURY, DAVID O. The Glass Giant of Palomar. 1939.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

ABEGGS HANDBUCH der anorganischen Chemie. Vierter Band, dritte Abteilung, vierter Teil, Lieferung 2. 1939.

Beilsteins Handbuch der organischen Chemie. Vierte Auflage. Neunundzwanzigster Band, erster Teil. 1939.

DAVISON, H. F. A Collection of Chemical Lecture Experiments. 1926.

FEIGL, FRITZ. Qualitative Analysis by Spot Tests. Second English Edition. 1939.

MATTHEWS, F. J. Boiler Feed Water Treatment. 1935.

MELLON, IBERT. Industrial Solvents. 1939.

SEDNA, LUDWIG. Das Wachs und seine technische Verwendung. Dritte Auflage. 1919.

TONGUE, HAROLD. A Practical Manual of Chemical Engineering. 1939.

VOGEL, ARTHUR I. A Text Book of Quantitative Inorganic Analysis. 1939.

WESTON, FRANK E. A Scheme for the Detection of the more Common Classes of Carbon Compounds. 1939.

COMMUNICATION CODES.

GAINES, HELEN FOUCHÉ. Elementary Cryptanalysis. 1939.

ELECTRICITY AND ELECTRICAL ENGINEERING.

ARDENNE, MANFRED VON. Cathode-Ray Tubes. 1939.

GEOLOGY.

RAISTRICK, A., AND C. E. MARSHALL. The Nature and Origin of Coal and Coal Seams. 1939.

MECHANICAL ENGINEERING.

A. S. M. E. Committee on Metal Cutting Data. Manual on Cutting of Metals. 1939.

RIPPER, WILLIAM. Ripper's Heat Engines. New Edition, Revised by A. T. J. Kersey. 1939.

SEVERNS, WILLIAM H., AND HOWARD E. DEGLER. Steam, Air, and Gas Power. 1939.

NAVAL ARCHITECTURE AND NAVIGATION.

CHAPELLE, HOWARD I. American Sailing Craft. 1939.

CULVER, HENRY B. Forty Famous Ships. 1936.

PHOTOGRAPHY.

ANDERSON, PAUL L. The Technique of Pictorial Photography. 1939.

PHYSICS.

SLATER, J. C. Introduction to Chemical Physics. First Edition. 1939. International Series in Physics.

STEVENS, BLAMEY. The Psychology of Physics. 1939.

SCIENTIFIC ESSAYS.

KAEMPFFERT, WALDEMAR. Science Today and Tomorrow. 1939.

SUGAR.

South African Sugar Year Book. 1938. Ninth Year of Publication.

RESOLUTIONS PASSED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF MR. FRANCIS T. CHAMBERS.

THE BOARD OF MANAGERS OF THE FRANKLIN INSTITUTE desires to express its deep sense of loss caused by the death of FRANCIS T. CHAMBERS, and to convey this formal expression of sympathy to his family in their bereavement.

Mr. Chambers first became connected with The Franklin Institute as a member in 1880. His interest in the work here lead to his election to the Board of Managers in 1913. From then until the time of his death, Mr. Chambers remained an interested and productive worker in the affairs of this old society.

As a regular attendant at Board meeting, until illness forced him to do otherwise, as an informed chairman of museum and endowment committees from time to time, and as a gentleman of quiet decision, Mr. Chambers brought to his membership in the Board of Managers qualifications which caused others to turn to him for opinions and counsel. But more, he was respected and esteemed by all for the personal characteristics which gained for him a wide circle of friends wherever he went, and in which he counted many of his fellow associates on the Board.

The Board of Managers wishes to record in its minutes this expression of sorrow and directs that a copy be sent to the family of Mr. Chambers, and that it be published in the JOURNAL OF THE FRANKLIN INSTITUTE.

December 20, 1939.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

THE DIFFERENCE IN THE ABSORPTION OF COSMIC RAYS IN AIR AND WATER AND THE INSTABILITY OF THE BARYTRON.*

BY

T. H. JOHNSON AND M. A. POMERANTZ.

Ehmert [1] and Auger, Ehrenfest, Freon and Fournier [2] have found that the intensity of the cosmic radiation depends not only upon the quantity of a given kind of matter traversed by the rays, but that it is a function of the distribution of that matter as well, the denser matter appearing to absorb the rays less. As an interpretation of these results Kulenkampf and Euler and Heisenberg [3] have pointed out that the instability of the barytron, predicted by Yukawa,[4] should give rise to a lower intensity when the time required for the secondary barytrons produced in the upper atmosphere to reach the apparatus is greater. The mean life predicted by Yukawa for the barytron at rest is $\tau_0 = 0.5 \times 10^{-6}$ sec., and because of the relativity transformation the stability appears to increase in proportion to the energy for energies large compared with the rest energy μc^2. A recent comparison of the cosmic-ray intensities and zenith angle distributions at two elevations by Ehrenfest and Freon [5] enabled these authors to compute a rest life of the order of 4×10^{-6} sec., or about ten times that predicted by Yukawa.

W. F. G. Swann has recently had erected at the Bartol Laboratory a cylindrical water tower three meters in diameter and 8.9 meters deep, with a room beneath for experimentation. He has generously placed this at our disposal for an investigation similar to that of Auger et al. in which we have had the advantage of making all measurements under favorable laboratory conditions at a single location. In these experiments the counting rate of a quadruple coincidence

* Reprinted from *The Physical Review*, **55**, 104 (1939).

[1] A. Ehmert, *Zeits. f. Physik*, **106**, 751 (1937).

[2] P. Auger, P. Ehrenfest, A. Freon and A. Fournier, *Comptes rendus*, **204**, 257 (1937).

[3] H. Euler and W. Heisenberg, *Ergeb. d. Exakt. Naturwiss.* (1938).

[4] H. Yukawa, *Proc. Phys.-Math. Soc. Japan*, **17**, 48 (1935); See also H. J. Bhabha, *Nature*, **141**, 117 (1938).

[5] P. Ehrenfest and A. Freon, *Comptes rendus*, **207**, 853 (1938).

counter train of large area but small angular aperture was recorded, first when it was directed vertically upwards through the 8.9 meters of water and the equivalent 10 meters of atmosphere, and then when it was inclined at the zenith angle $\zeta = \sec.^{-1}(1.89) = 58°$. Lead plates for eliminating the soft component were stacked between counters to a thickness of 17 cm. and 38 cm., respectively, in two independent experiments. In both instances the counting rates in the inclined position were less than those in the vertical; if j_ζ and j_v designate the respective intensities the experiments gave

$$j_\zeta/j_v = 0.60 \pm 0.02 \text{ with } 17 \text{ cm. lead}$$

or

$$= 0.68 \pm 0.02 \text{ with } 38 \text{ cm. lead.}$$

In order to evaluate the mean life of the barytron from these data we have used two types of calculation, both of which involve assumptions which must be regarded as more or less arbitrary in the present state of our knowledge. Barytrons incident at zenith angle ζ are assumed to have originated as secondaries at an atmospheric depth $h = fH \cos \zeta$ where H is the depth of the homogeneous atmosphere ($= 8 \times 10^5$ cm.) and f is a fraction of the order of 1/10; the actual height above sea level, corresponding to this depth, is $x = H \log (\sec. \zeta/f)$. The mean life of barytrons of energy $\epsilon\mu c^2$ is $\tau_0\epsilon$, and if a ray loses energy by ionization at the constant rate $i\mu c^2$ per cm. in normal air, the probability of a ray of initial energy $\epsilon\mu c^2$ reaching seal level without disintegrating is given by

$$P(\epsilon, \zeta) = \exp - [(H \sec. \zeta/c\tau_0\epsilon) \times \log (\epsilon/ifH - 1)/(\epsilon/iH \sec. \zeta - 1)]. \quad (1)$$

In the first calculation we let $j(\epsilon)d\epsilon$ represent the number of barytrons per cm.^{2} per sec. per unit solid angle whose initial energies lie between $\epsilon\mu c^2$ and $(\epsilon + d\epsilon)\mu c^2$, a function which may be supposed independent of the direction, so that the number of rays of these initial energies which reach sea level in the vertical direction is $j(\epsilon)P(\epsilon, 0)$. The experiments of Ehmert [1] and Wilson [6] show the latter function to be of the form $A/(\epsilon - iH(1 - f))^\gamma$ where $2 < \gamma < 3$. If $\alpha\mu c^2$ is the energy required to penetrate the lead shield, the intensity in the vertical direction under 8.9 meters of water and the atmos-

[6] V. Wilson, *Phys. Rev.*, **53**, 337 (1938).

phere may be expressed by

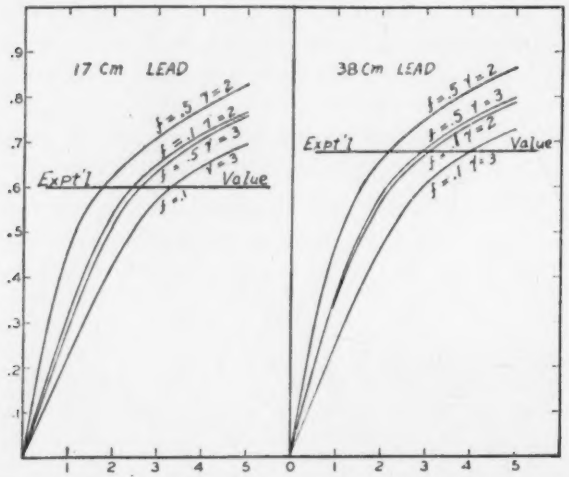
$$j_v = \int_{iH(1.89-f)+\alpha}^{\infty} j(\epsilon)P(\epsilon, 0)d\epsilon$$
$$= A/(\gamma - 1)(\alpha + 0.89iH)^{\gamma-1}, \qquad (2)$$

whereas that in the inclined position is given by

$$j_\zeta = \int_{iH(\sec.\,\zeta-f)+\alpha}^{\infty} j(\epsilon)P(\epsilon, \zeta)d\epsilon. \qquad (3)$$

We have chosen as a value of the rest mass of the barytron one-tenth of the proton mass, and with the rate of loss of energy by ionization proportional to the inverse square of the velocity we find $\alpha = 3.6$ for 17 cm. lead, 6.4 for 38 cm. lead, and $iH = 20$. The values of j_ζ/j_v calculated for various values of τ_0, for the cases where $f = 0.1$ and 0.5 and $\gamma = 2$ and 3, are shown in Fig. 1. Agreement with our measured values occurs for values of τ_0 between 2 and 4×10^{-6} sec.

FIG. 1.



Ordinates: calculated values of j_ζ/j_v. Abscissae: the rest life τ_0 in microseconds.

The second calculation is concerned with the disintegrations of rays whose energies lie within the narrow band of

energies which penetrate the 17-cm. lead absorber, but fail to pass through the 38-cm. shield; this calculation is independent of the energy distribution and applies to only those rays whose initial energy is given by

$$\epsilon_1 = iH(1.89 - f) + \bar{a},$$

where $\bar{a}$ is the average of the minimum energies for penetration of the two thicknesses of lead. In this calculation τ_0 is obtained from the equation

$$\eta \equiv \frac{j_v(17) - j_v(38)}{j_\xi(17) - j_\xi(38)} = P(\epsilon_1, 0)/P(\epsilon_1, \xi). \qquad (4)$$

The order of runs in these experiments was not arranged to give an accurate value of η, but we can give $\eta = 2.5$ as a preliminary value from which we calculate $\tau_0 = 2.6 \times 10^{-6}$ sec. with $f = 1/10$ or $= 2.4 \times 10^{-6}$ sec. with $f = 0.5$. The result is insensitive to the choice of f.

We wish to acknowledge helpful discussions with Dr. C. G. Montgomery and to state that the Carnegie Institution of Washington contributed to the support of the experiments.

THE EAST-WEST ASYMMETRY OF THE COSMIC RADIATION AT VERY HIGH ELEVATIONS NEAR THE EQUATOR.*

BY

T. H. JOHNSON AND J. G. BARRY.

In order to obtain further evidence as to the nature of the primary cosmic rays associated with the soft component we have made a series of balloon flights near the equator with directionally selective recording instruments for determining the east-west asymmetry at very high elevations. The asymmetry at sea level leads almost inevitably to the conclusion that the primaries producing the hard component must be heavy positive particles such as protons.[1] On the other hand the success of the multiplicative theory in accounting for the transition effect in the upper atmosphere is circumstantial evidence that the primaries of the soft component are

* Reprinted from *The Physical Review*, **55**, 503 (1939).

[1] T. H. Johnson, *Phys. Rev.*, **54**, 385 (1938).

electrons. Such an electron component, if it is to satisfy the condition of an equilibrium of potential at the cosmic-ray source and at the same time preserve the neutrality of interstellar space, must consist of an equal number of positives and negatives and there would be no asymmetry of the soft component. If, on the other hand, the primaries of the soft component were protons a very considerable asymmetry would be expected; a western intensity of the order of eight times the eastern can be predicted at the elevations attained on these flights if one makes use of an extrapolation of the energy distribution of the primary rays deduced from the latitude effect.[2] Thus comparatively crude asymmetry measurements should enable one to distinguish between primary protons and electrons.

Each instrument carried by the balloons consisted of a triple coincidence train of Geiger-Mueller counters inclined 60° from the vertical, a barograph and a radio transmitter. The signals were automatically recorded on a paper tape at the receiving station and it was unnecessary to recover the balloons. Cosmic-ray coincidences were transmitted as "dots" whereas the barometric pressure was determined from the spacing of a pair of "dash" signals keyed at ten-second intervals by the rotation of a small motor.[3] A third contact from the motor was in series with a half-shaded photo-cell and this signal was transmitted only on those cycles when the photo-cell was exposed to the direct rays of the sun, thus indicating the orientation of the counter train. The instrument was carried by two strings of balloons attached to either end of a long horizontal bar and the entire rigging was rotated in azimuth by a pair of vanes acted upon by the air currents associated with the ascent. The instrument turned somewhat irregularly at speeds varying from one-half to three revolutions a minute at the take off and at lower speeds at the top of the flight. Ten flights of this type were sent up from the Barro Colorado Island Laboratory of the Institute for Research in Tropical America, located in the Panama Canal Zone, and complete records were obtained from five of these. The results are summarized in Table I, which contains the

[2] T. H. Johnson, *Rev. Mod. Phys.*, **10**, 193 (1938).

[3] T. H. Johnson and S. A. Korff, *Rev. Sci. Inst.*, **11**, 82 (1939).

TABLE I.

Data from counters at atmospheric depths less than one and one-half meters of equivalent water.

Flight Number	Minimum Depth Meters of Water	East			West			r_w/r_e
		Counts	Time Rate		Counts	Time Rate		
			min.	r_e		min.	r_w	
110	0.40	1091	14.6	75	1685	18.5	91	1.21
112	0.45	133	5.0	26.6	283	7.2	39.4	1.54
113	0.60	254	9.1	28	409	12.4	33	1.18
115	0.50	472	11.8	40	973	18.3	53.2	1.33
B	0.33	478	13.3	36	736	18.0	41	1.14
Total		2428	53.8	45	4086	74.4	55	1.22

data from the portions of the records for which the atmospheric depth was less than one and one-half meters of equivalent water. At this depth the cosmic radiation entrant from the chosen zenith angle has its intensity maximum. The numbers of counts for each interval of the record have been corrected for the variation of intensity with elevation and the figures represent an average of the counting rates for the upper portion of the flight, the minimum depths of which are indicated in the table.

The ratios of the western to eastern intensities are given in the last column of the table from which it is noted that the average western excess is 22 per cent. This is not as great as would have been expected if the primaries were all protons but indicates that about ten per cent. of the high elevation intensity is produced by unbalanced positives. This may very well represent the part of the high elevation intensity attributable to the hard component. The soft component would then be made up of equal numbers of positive and negative electrons.

These studies have been carried out under a grant from the Carnegie Institution of Washington. We wish also to acknowledge the cooperation of Mr. James Zetek, Director of the Barro Colorado Laboratory, and of Colonel S. B. Akin of the U.S.A. Signal Corps.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Microdetermination of Cholesterol in Serum.—HERBERT K. ALBER AND J. T. BRYANT. (Microchemical Laboratory of the Biochemical Research Foundation of the Franklin Institute, Philadelphia, Pa.) The analytical details of cholesterol determination in blood serum have been studied carefully in order to supply reliable data by biochemical methods.

In reviewing the extensive literature, a search was made for a method in which the cholesterol could be isolated as digitonide free from by-products which would interfere in the colorimetric estimation, small amounts of free and total cholesterol could be determined accurately, and serial analyses could be carried out without too much special equipment not ordinarily available. The method finally decided upon was essentially that of Schoenheimer and Sperry (*J. Biol. Chem.*, **106**, 745 (1934)) and G. O. Brun ("Cholesterol Content of the Red Blood Cells in Man." H. K. Lewis and Co. Ltd., London, 1939) with modifications, some of which had been suggested by Fitz (*J. Biol. Chem.*, **109**, 523 (1935)) and some of which have been confirmed by Sperry in the meantime (private communication; *Amer. J. Clin. Pathol.*, **8**, 91 (1938)).

The modified method used in this laboratory is described in detail, with some of the modifications from the original procedures being discussed, because it is believed that this method offers some advantages over other routine methods.

Reagents Used:

Acetone-absolute alcohol mixture, 1 : 1, commercial grade (acetone must be freshly distilled).

Ether, dry, reagent grade (peroxide free).

Acetone-ether mixture, 1 : 2.

Digitonin, 0.2 per cent. solution; 0.2 g. of digitonin (Merck, Inc.) dissolved in 100 cc. of 50 volume per cent. alcohol.

Potassium hydroxide, 33 per cent. solution; 10 g. of pellets are dissolved in 20 cc. of distilled water.

Hydrochloric acid, 5 per cent.; 15 cc. of conc. HCl (13 molar) are diluted to 100 cc. with distilled water.

Acetic acid, 99.9 per cent. Eastman No. 763.

Acetic anhydride. Eastman No. 4.

Sulfuric acid, conc.

Naphthol Green B Solution (National Aniline and Chemical Company, Inc., New York); 0.1 g. in 1000 cc.; the solution is exposed to the light under which the measurements in the colorimeter are performed. This solution is diluted with distilled water until the depth of color corresponds to that obtained with 0.125 mg. cholesterol.

Standard cholesterol solution, see under discussion.

Procedure for the Determination of Free and Total Cholesterol in Serum:

Extraction: The untreated blood is centrifuged at 2000 r.p.m. for 15 minutes, and the clear serum is separated immediately from the clot. One-half cc. serum is pipetted slowly into approximately 6 cc. of the acetone-alcohol mixture contained in a 10 cc. volumetric flask. The mixture is then heated with constant shaking to boiling on a water bath and made up to the mark with acetone-alcohol mixture; the stoppered flask is inverted at intervals to allow complete extraction. After attaining room temperature, the solution is made up to volume. The contents of the flask should be a water-clear solution over a whitish precipitate; it is filtered through a small, coarse filter paper (No. 4, Whatman) into a test tube, which is then stoppered to prevent loss of solvent.

Precipitation: Free Cholesterol: 5 cc. of this extract, corresponding to 0.25 cc. of the original serum, are pipetted into a 15 cc. centrifuge cone and 2 cc. of the digitonin solution added. A small glass stirring rod is used for mixing and remains in the tube during the precipitation. Both are placed into a suitable container (preserving jar) and the cover closed, so that no solvent is lost during the 12 hours (minimum interval) of necessary standing.

Total Cholesterol: 2 cc. of the extract, corresponding to 0.1 cc. of the original serum, are pipetted into a 15 cc. centrifuge cone and one drop of 33 per cent. potassium hydroxide is added. The mixture is stirred with a small glass rod, which remains in the centrifuge cone, and kept at a temperature of 37 to 40° C. for at least 30 minutes in a closed container, partially filled with sand. The centrifuge cone is removed, and the excess of potassium hydroxide in the saponification mixture is neutralized with 5 per cent. hydrochloric acid, using phenolphthalein as indicator. This final mixture may contain some potassium chloride as precipitate. Two cc. of digitonin are added and the whole is stirred in order to dissolve the salt. For the complete precipitation of the total cholesterol the mixture is allowed to stand for at least 12 hours in the closed container.

Washing: After the cholesterol is precipitated as the digitonide, the determinations for the total and the free cholesterol are carried out in the same manner. The stirring rod is removed from the centrifuge cone and kept on a rack so that it may be replaced into the correct centrifuge cone after centrifugation, for which 15 minutes at 2000 r.p.m. are satisfactory. The supernatant liquid over the digitonide precipitate is drawn off by means of a capillary pipette connected to a suction device, an ordinary water pump being adequate. The precipitate is washed with 2 cc. acetone-ether mixture, stirred, centrifuged, and the supernatant wash liquid removed as mentioned above. The precipitate is washed twice with dry ether, the latter being removed each time as completely as possible. The centrifuge cone is brought into a cold water bath the water of which is slowly heated to boiling, thus preventing loss of material by too rapid evaporation.

Color Development by the Liebermann-Burchard Reaction: The dry cholesterol digitonide is dissolved in 0.5 cc. glacial acetic acid, the solution being hastened by placing the centrifuge cone into a water bath of from 60 to 70° C. After attaining room temperature, 1 cc. acetic anhydride and 0.1 cc. concentrated sulfuric acid are added and the solution mixed thoroughly with the stirring rod. In two minutes intervals, the next tubes are treated in the same manner. The color is

compared 27 to 33 minutes after the addition of the sulfuric acid. It is understood that each individual sample is compared after standing for approximately the same length of time, i.e., 30 minutes. For this purpose, 0.5 cc. of the color solution are used for rinsing the 1 cc. micro cup of an ordinary Dubosq colorimeter, the cup being filled finally with the remaining part of the solution. The diluted Naphthol Green B solution serves for the comparison, a 71A Wratten filter being used in the colorimeter.

Since the dye solution corresponds to a certain amount of cholesterol, e.g., in this laboratory to 0.125 mg., the free and total cholesterol can be calculated from the colorimeter readings in the usual manner. It is desirable to compare frequently the color of the dye solution with that of the standard cholesterol solution. Although the latter has been found to be stable for at least 4 weeks, over a period of 4 months a change of 5 per cent. has been observed. The dye solution is best kept in the dark.

Discussion:

Several modifications have been incorporated into the original Schoenheimer and Sperry procedure as mentioned in the introduction.

(*a*) The clear serum is pipetted into a cool mixture of acetone-alcohol for the extraction instead of the previously recommended hot mixture. In the latter case, clots were formed and the extraction was not complete. Private communication with Sperry revealed that he had come to the same conclusion.

(*b*) For the free and total cholesterol determinations together, 0.5 cc. of serum were taken for analysis. Larger volumetric flasks could be used and the measurements were made easier than in the procedure of Schoenheimer and Sperry (l.c.) which starts with 0.2 cc. of serum.

(*c*) The 0.2 per cent. digitonin solution, prepared according to the original procedure, was found to be so unstable and so complicated to prepare that various alcohol-water solutions were tested for their efficiency in precipitating the cholesterol, and for their stability. All digitonin solutions were 0.2 per

cent. with regard to their digitonin content. It was found that 30 volume per cent. alcohol solutions gave complete precipitation of the cholesterol digitonide (recovery 97–101 per cent.), but a sediment formed in the reagent within a week. Fifty volume per cent. alcohol solutions gave complete precipitation (recovery 99–101 per cent.), and no sediment could be observed even after several months. Seventy volume per cent. alcohol solutions gave incomplete precipitations (recovery 85–101 per cent.), as did 90 volume per cent. solutions (recovery less than 60 per cent.), the latter giving additional precipitates after adding more water. In these experiments two types of digitonin were tested, one obtained from Merck, Inc., and the other from Hoffman-La Roche, Inc. As precipitants, they were found equally efficient within the limits of experimental error. In order to simulate the conditions of treating a serum extract, 0.250 mg. cholesterol were dissolved in 5 cc. of the acetone-alcohol mixture, and two cc. of the alcoholic solutions of digitonin were added. In general, these findings are in agreement with the experiments of Brun (l.c.).

In these series of experiments it was observed that approximately 15 per cent. of water must be present in the solution in order to give complete precipitation.

(*d*) It has been stated under "procedure" that 30 minutes are sufficient to saponify the total cholesterol at 37 to 40° C. Due to the arrangement of analyses in this laboratory, it was found convenient to increase this time interval to 5 hours, a step which apparently did not influence the ultimate recovery of cholesterol.

(*e*) The amounts of glacial acetic acid and acetic anhydride were reduced to 0.5 cc. and 1 cc. respectively, but not the sulfuric acid, since it was inconvenient to measure smaller quantities than 0.1 cc. of concentrated sulfuric acid accurately. (The titration stand of Neale and Forbes, manufactured by Phipps and Bird, Inc., Richmond, was used successfully for measuring the acids with the advantage that the analyst is not annoyed by the fumes.) For future work it is intended to make up the acid reaction mixture, sulfuric acid and acetic anhydride, and add it to the dissolved cholesterol, as has been

suggested by experiments of A. Bloch (*Biochem. Zeitschrift*, **257**, 171 (1933)).

(*f*) The use of an ordinary colorimeter of the Dubosq type in connection with the 1 cc. micro cups should help to introduce this method as a routine method into clinical laboratories, as suggested by Fitz (l.c.) and by Shapiro, Lerner, and Posen (*Proc. Soc. Exper. Biol. Med.*, **32**, 1300 (1935)). The photometer recommended by Schoenheimer and Sperry (l.c.) has certainly some advantages, but is in general too expensive for the average laboratory. The results obtained with both instruments are comparable in accuracy.

(*g*) It is advisable to check the accuracy of the described method and the stability of the dyestuff standard from time to time. A cholesterol digitonide standard solution is prepared as follows: 50 mg. of cholesterol, Merck, Inc., purified according to Noyons (*Biochem. Zeitschrift*, **298**, 391 (1938)) and 150 mg. digitonin, Hoffman-La Roche, Inc., are dissolved in 100 cc. glacial acetic acid. 0.5 cc. of this solution, corresponding to 0.250 mg. cholesterol, give a color within the range most frequently met in serum extracts. By further dilution with equal parts of glacial acetic acid, the range of 0.125 mg. cholesterol is accessible.

Experimental Part:

In order to establish the *accuracy* of the modified procedure, solutions of cholesterol in acetone-alcohol, corresponding to from 0.100 to 0.250 mg. cholesterol, were taken through all of the manipulations except the extraction and the recovery was calculated; in Table I the results are shown as obtained in weekly intervals and not in one special series of experiments.

In these experiments the lowest recovery was 96 per cent., the highest recovery 102 per cent., the mean recovery 99 per cent., and the average deviation from the mean ± 2 per cent. This accuracy agrees very well with that of more complicated procedures described in the literature. The error of the color comparison in the ordinary colorimeter forms the major part of the total error; in a special series of experiments on pure cholesterol solutions it was found to be within ± 1.5 per cent.

The above accuracy refers to the determination of the free cholesterol in serum only. The accuracy of the procedure for the total cholesterol in serum was not specially determined, since the cholesterol esters in blood behave differently from chemically pure cholesterol acetate or palmitate. Thus, an additional error for the saponification will enter the accuracy of the method for the total cholesterol.

TABLE I.

Recovery of Cholesterol.

Cholesterol in mg.		Recovery in per cent.	Cholesterol in mg.		Recovery in per cent.
Used.	Recovered.		Used.	Recovered.	
.100	.098	98	.250	.249	100
.100	.096	96	.250	.252	101
.200	.204	102	.250	.247	99
.200	.201	100	.250	.243	97
.200	.204	102	.250	.250	100
.200	.198	99	.250	.254	102
.250	.242	97	.250	.252	101
.250	.240	96	.250	.243	97
.250	.244	98	.250	.240	96

The *precision* of the modified procedure was determined separately for the free and the total cholesterol by duplicate analyses of blood samples kindly submitted to us by Dr. J. B. Wolffe, Philadelphia, Pa. The blood was drawn from patients with various types of diseases or from normal persons, each sample split at least into two parts and put into a series of numbered test tubes. Since all these steps were carried out outside of this laboratory, the duplicate samples can be considered as real unknowns to the analyst, and are significant for the reproducibility of the procedure.

Since it would be too extensive to report all the duplicate analyses in detail, the results of the calculations are given here. From 72 duplicate analyses for *free* cholesterol in serum, the average deviation from the mean value was ± 1.5 mg. per cent. or ± 1.9 per cent. The maximum deviation from the mean value was 9.5 per cent. (7.0 mg. per cent.), five determinations of the 72 having an error of more than 5 per cent., mainly towards the beginning of the work. The range of free cholesterol found was between 44 and 120 mg. per cent.

The precision of the modified procedure for the *total* cholesterol in serum was determined from 68 duplicate analyses on unknown samples submitted as mentioned above. The average deviation from the mean value was ±5.0 mg. per cent., or ±2.3 per cent. The maximum deviation from the mean value was 24.5 mg. per cent. (10.7 per cent.), six determinations having an error of more than 5 per cent. The amounts of total cholesterol in serum ranged from 131 to 325 mg. per cent.

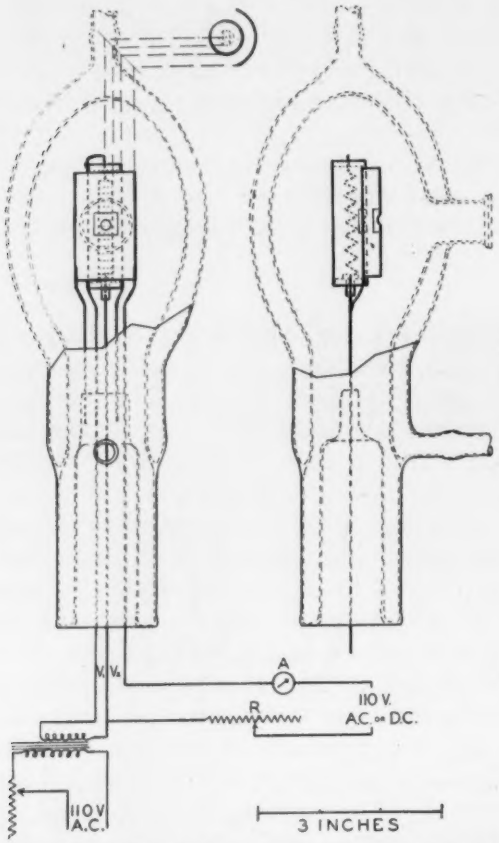
Because of the comparatively inexpensive equipment, and the accuracy and precision of the method, this modified procedure has been found to be valuable for routine analyses.

A Hydrogen Arc for Absorption Spectroscopy.—A. J. ALLEN AND R. G. FRANKLIN. (*Journal of the Optical Society of America*, **29**: 453, Oct. 1939.) The determination of absorption spectra is greatly facilitated by the use of a constant, intense source of light which emits a continuous spectrum in the region under study and which is of the shape of a point or slit according to the requirements of the spectrograph used. A low voltage hydrogen arc with these characteristics has been constructed for use in the ultraviolet region. This arc is reliable and easy to operate, compares favorably in intensity with an intense spark between iron electrodes and has the additional advantage of being inexpensive to construct.

A schematic drawing of the essential elements of the arc is shown in Fig. 1. The cathode consists of a strip of nickel screen, made into a corrugated form and dipped into an oxide coating material. The cathode is surrounded by a nickel cylinder with an orifice which can be adapted to various sizes and shapes. The anode is a rectangular piece of molybdenum with an orifice to correspond to that of the cathode. The cathode-anode assembly is placed in a Pyrex bulb onto which a quartz window is sealed with Glyptal lacquer. The bulb is completely water-jacketed for cooling. Ordinary tank hydrogen at a pressure of 4 to 6 mm. of mercury has been found to be satisfactory for filling the arc. Either alternating or direct current may be used. The arc voltage is

approximately 40 volts and the arc current 1.0 to 1.5 amperes. The filament carries a current of 10 to 12 amperes at 3.5 to 4.0 volts.

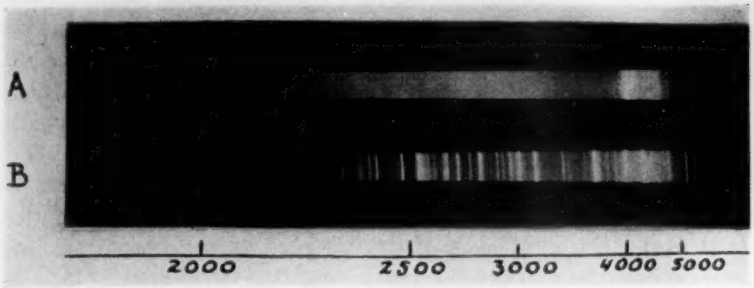
FIG. 1.



Schematic drawing of low voltage hydrogen arc. V_1—filament voltage, 3.5–4.0 volts; V_2—arc voltage 40.0 volts; *A*—ammeter to measure arc current, 1.0–1.5 amperes; and *R*—variable resistance, 100 ohms, — 2.0 amperes. (Courtesy Journal of the Optical Society of America.)

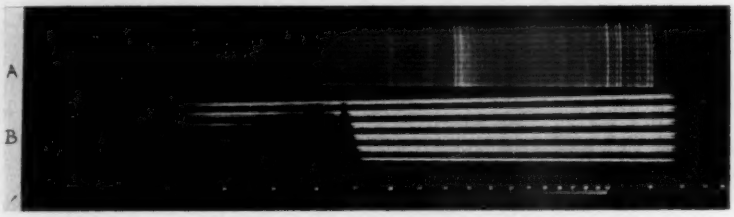
Photographs of the continuous spectrum produced by one of these arcs, and of the spectrum of a mercury arc for comparison, are shown in Fig. 2. In the original negative the hydrogen arc spectrum is clearly seen as far as 1850 A.U. In Fig. 3 are spectrograms taken with a Bausch and Lomb spectrograph using Hilger notched echelon cells.

FIG. 2.



(*A*) Spectrogram obtained with low voltage hydrogen arc, using a Hilger E31 spectrograph. (*B*) Mercury arc spectrum for comparison. (Courtesy Journal of the Optical Society of America.)

FIG. 3.



(*A*) Spectrogram taken with Bausch and Lomb medium size spectrograph with echelon cells filled with water. Exposure 5 seconds. (*B*) Absorption spectrum of toluene (approximately 0.01 per cent. solution in alcohol). Sector setting of 15. Exposure 1 minute. Eastman 33 plates used. (Courtesy Journal of the Optical Society of America.)

Complete instructions are given in the original article for making this arc, and data are also given from which comparisons with other light sources can be made.

Derivatives of Aminomethanethiol.—ARTHUR BINZ AND LELAND H. PENCE. (*Journal of the American Chemical Society*, **61**: 3134, 1939.) The disinfecting properties of formaldehyde long have been recognized. Similar properties have been noted in many compounds containing sulfur. The reported inhibitory action on the growth of malignant tumors, and other physiological reactions instigated by some sulfur

containing compounds, e.g., mustard gas [bis(2-chloroethyl) sulfide] and certain sulfoxides and sulfones, have also aroused the interest of a number of investigators.

Compounds which could be obtained from formaldehyde, and which contained sulfur, were therefore considered to be worthy of investigation. Hydrogen sulfide was known to react with formaldehyde to produce hydroxymethanethiol ($HOCH_2SH$), but this compound is unstable. In order to obtain stable compounds of this type, the authors decided to attempt the synthesis of derivatives of the corresponding aminomethanethiol (H_2NCH_2SH).

Piperidine was treated with formaldehyde to yield 1-piperidinemethanol. Treatment of this substance with hydrogen sulfide at 65° C. gave 1-piperidinemethanethiol (I). When the reaction was performed at 0° C. the sulfide, 1,3-di-(1′-piperidine)-2-thiapropane (II), was produced. In a similar manner formaldehyde reacted with morpholine to yield 4-morpholinemethanol. The latter, on treatment with hydrogen sulfide in a hydrochloric acid medium, yielded 4-morpholinemethanethiol (III); in the absence of acid, the sulfide, 1,3-di-(4′-morpholine)-2-thiapropane (IV), was obtained. Simultaneously with (III) was formed the by-product, 1,7-di-(4′-morpholine)-2,4,6-trithiaheptane (V); a side-reaction yielding 3-(4′-morpholine)-2-thiapropanethiol (VI) occurred during the synthesis of (IV). Diethanolamine and formaldehyde in the cold produced methanoldiethanolamine, which on treatment with hydrogen sulfide gave an amorphous white solid (compound (VII)) containing 52 per cent. sulfur. Since the analysis showed that there were 7 sulfur atoms associated with each nitrogen atom, the possible presence of a molecular combination between diethanolaminemethanethiol and trithioformaldehyde, $(CH_2S)_3$, was indicated. But the possibility of such an existence of trithioformaldehyde in (VII) was quite definitely excluded, after comparing the properties of the latter with those of pure trithioformaldehyde. The two compounds showed marked differences with respect both to their solubility in various solvents, and their behavior when subjected to sublimation. Not a trace of trithioformaldehyde could be sublimed out of (VII). Since the CH_2S-units do not appear to be present in the form of the cyclic trithio-

formaldehyde, then they must be in a long 14-membered chain containing alternate carbon and sulfur atoms. A compound with such structure would be named 13-diethanolamine-2,4,6,8,10,12-hexathiatridecanethiol. When seven parts of formaldehyde were used with one part of diethanolamine, the subsequent reaction with hydrogen sulfide produced a compound (XIII) whose analysis showed a ratio of one nitrogen atom to 14 sulfur atoms.

Of interest from a chemical standpoint were the reactions of mercuric chloride on 1-piperidinemethanethiol (I) and 4-morpholinemethanethiol (III) in alcoholic solutions. In both cases the amines were split off to leave a residue of the same mercuric salt of hydroxymethanethiol, mercuric dimercaptomethanol, which readily lost the elements of water to give the 6-membered ring, mercuric di-(mercaptomethyl) ether. Although this precipitate was very insoluble in water, an aqueous suspension of it yielded mercuric sulfide on treatment with hydrogen sulfide. Corresponding reactions were observed when the thiols were treated with cupric acetate. But in this case the resulting cupric di-(mercaptomethyl) ether immediately lost the elements of formaldehyde and gave a precipitate, the analysis of which indicated it to be the 4-membered ring, cupric methylene dimercaptide. Although this compound was so insoluble that hydrogen sulfide would not precipitate copper sulfide from its aqueous suspension, such reaction did occur upon the addition of sodium sulfide solution.

Many of the compounds were quite toxic. 1-Piperidinemethanethiol (I) and 1,3-di-(1′-piperidine)-2-thiapropane (II) in 0.04 per cent. aqueous solution killed paramecia immediately, and daphnia in 20 minutes. Minimum lethal doses of some of the compounds when injected intravenously into mice were found to be as follows:

4-Morpholinemethanethiol (III)	0.025 mg./g. body weight
1,3-Di-(4′-morpholine)-2-thiapropane (IV)	0.021
Compound (VII)	0.165
1-Piperidinemethanethiol hydrochloride (XI)	0.05
1,3-Di-(1′-piperidine)-2-thiapropane dihydrochloride (XII)	0.083
Thiocetic acid	0.125

The minimum lethal doses of the following compounds, when injected subcutaneously into rabbits, are submitted for the sake of comparison:

Piperidine	0.5 mg./g. body weight
1-Methylpiperidine	0.4
1-Ethylpiperidine	0.3
Coniine (1-Propylpiperidine)	0.09

Thus most of these compounds were found to have a greater toxicity than coniine, without possessing the characteristic side chain of the latter.

BOOK REVIEWS.

RUBBER RED BOOK, DIRECTORY OF THE RUBBER INDUSTRY, 1939 Edition. 420 pages, 15 × 23 cms. New York, The Rubber Age. Price $5.00.

Industrial directories are becoming more and more popular in commercial as well as industrial and technical activities. To be able to obtain quickly, accurate information on such industries as is represented by the rubber industry is an asset whose value is beyond measurement. As a source of information, directories undoubtedly are rated in first place.

Those who have used the 1937 Red Book will find that this 1939 edition is much larger and more valuable for reference. New sections include a comprehensive list, alphabetically, of individuals actively engaged in the rubber industry, sales agents and suppliers' branch offices, a list of technical journals, and comprehensive data on technical and trade organizations.

The arrangement of the material in this book is such that information should be easy to get. An alphabetical list of manufacturers is followed by the same list classified as to products of manufacturers. Canadian manufacturers are also listed. Then there are lists of machinery manufacturers both classified and alphabetical. What should be very helpful to those not engaged directly in the industry are the data on rubber chemicals and compounding materials which include trade and brand names and suppliers' names. Other sections are devoted to fabrics and textiles, crude rubber, miscellaneous types of rubber, rubber latex, consulting technologists, etc. There are many advertisements and a subject index. All information necessary is presented in at least two ways so that the book is suitable for use from whatever angle queries may arise.

R. H. OPPERMANN.

PROBLEMS IN MECHANICS, by G. B. Karelitz, J. Ormondroyd and J. M. Garrelts. 271 pages, illustrations, 16 × 24 cms. New York, The Macmillan Company, 1939. Price $2.50.

A knowledge of theory seldom if ever is fruitful without a knowledge of application. This is particularly true in engineering. Furthermore, it is well recognized that application of theory must be continually exercised in order to be and to become proficient. Too much stress cannot be laid on these points, for today more than ever the engineer is called upon to be very active in his field. It is one of the duties, therefore, for the engineer to be continuously alert.

"Problems in Mechanics" may be viewed as a tool for this purpose. As its name implies the book consists of just that—problems for exercise. The first 50 pages are devoted to statements outlining the theorems useful in the solution of the list of problems which comprise the rest of the book. These cover some 200 more pages and are divided into three parts—statics, kinematics, and dynamics. With regard to statics, both plane and space statics are given space, the former including a number of problems on trusses and cables and there is a segregation

of problems on friction. Another section here is on center of gravity where problems on the first and second moments of areas can be found.

Part two covers kinematics of a point and kinematics of a rigid body, in rotation about a fixed axis and motion parallel to a fixed plane. Problems dealing with relative motion of a point and in composition of rotations of a rigid body are also here. The first sections of the third part have to do with the application of the differential equations of Newton to the motion of particles and to rotation and plane motion of rigid bodies. Later there are given problems involving the principles of work and energy, impulse and momentum, and motion of the center of gravity. An appendix gives tabular data helpful in the solutions. In general the problems are well conceived and arranged. The book can be useful for the purposes set forth to the student and engineer.

R. H. OPPERMANN.

WAVELENGTH TABLES, by George R. Harrison. 429 pages, plates, 20 × 28 cms. New York, John Wiley & Sons, Inc. 1939. Price $15.00.

Here is a book which presents the results of an enormous amount of work. It is comprised of tables giving the wave length, the intensity in arc, spark or discharge tube, the stage of ionization of the parent atom when the line has been classified in a term array, and the wave length authority, for each of the most important known spectrum lines emitted between 10,000 and 2,000 angstroms by atoms in the first two stages of ionization. Such information is invaluable when the spectrum of an element is being studied for classification purposes especially when chance lines not arising from the element in question must be eliminated.

The introduction to the work is very full in explanatory matter and shows not only the great magnitude of the exposition but it gives detailed information on the reasons for omitting certain lines from the tables, a description of the tables, the accuracy of values, apparatus and methods used to obtain the results here recorded, and the various factors considered throughout the work. In compiling the tables the literature for all previous wave length measurements on atomic lines was carefully examined. Then measurements were made to check this data, the agreeing values recorded, and the disagreeing values given further measurements and examination before arriving at a figure for the record. There are also included some data not previously given in the literature, which are purely tentative. All data is marked in some manner for identification. This work is somewhat indicative of the knowledge so far obtained with relation to what yet is unknown. The arrangement of the data is such that any worker in this field should have little trouble in locating desired information quickly.

R. H. OPPERMANN.

VAPOR CHARTS AND SPECIAL TABLES FOR TURBINE CALCULATIONS, by Frank O. Ellenwood and Charles O. Mackey. 43 pages, plates, 22 × 29 cms. New York, John Wiley & Sons, Inc., 1939. Price $2.50.

When extreme accuracy is not necessary and when theory is well understood, the use of charts in calculations is a great time saver. This was early recognized as is evident from the large number of old charts still in use. One of these is the steam chart published in 1914 by the senior author of the book at hand, copies of

which may be found in many engineering organizations today. The present book replaces the 1914 book with far more extensive data and a change in method. Using specific enthalpy as the ordinate and specific volume as the abscissa, a logarithmic volume scale is used instead of the uniform scale as in the original. The volume scale runs from .05 to 3500 cu. ft. per lb. and there is covered a total change of enthalpy of 600 Btu. per lb. The pressures range from 5500 lb. per sq. in. down to .18 inch of mercury and the temperatures from 1200° to 32° F.

But in addition to this, the book includes charts on the dynamic properties of water, ammonia, freon, and mixtures of air and water vapor. On page 26 examples of the use of the charts can be found. There are also psychrometric charts, and tables showing jet velocity from an ideal nozzle for each Btu. and for each tenth of a Btu. These charts and tables bound up in book form, provide a ready assistance to engineers making calculations involving these fluids.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 661, Tests in the Variable-Density Wind Tunnel of the N.A.C.A. 23012 Airfoil with Plain and Split Flaps, by Ira H. Abbott and Harry Greenberg. 9 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Section characteristics for use in wing design are presented for the N.A.C.A. 23012 airfoil with plain and split flaps of 20 percent. wing chord at a value of the effective Reynolds Number of about 8,000,000. The flap deflections covered a range from 60° upward to 75° downward for the plain flap and from neutral to 90° downward for the split flap. The split flap was aerodynamically superior to the plain flap in producing high maximum lift coefficients and in having lower profile-drag coefficients at high lift coefficients.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 667, Determination of the Profile Drag of an Airplane Wing in Flight at High Reynolds Numbers, by Joseph Bicknell. 9 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Flight tests were made to determine the profile-drag coefficients of a portion of the original wing surface of an all-metal airplane and of a portion of the wing made aerodynamically smooth and more nearly fair than the original section. The wing section was approximately the N.A.C.A. 2414.5. The tests were carried out over a range of airplane speeds giving a maximum Reynolds Number of 15,000,000. Tests were also carried out to locate the point of transition from laminar to turbulent boundary layer and to determine the velocity distribution along the upper surface of the wing.

The profile-drag coefficients of the original and of the smooth wing portions at a Reynolds Number of 15,000,000 were 0.0102 and 0.0068, respectively; i.e., the surface irregularities on the original wing increased the profile-drag coefficient 50 percent above that of the smooth wing.

Report No. 670, Tensile Elastic Properties of 18 : 8 Chromium-Nickel Steel as Affected by Plastic Deformation, by D. J. McAdam, Jr., and R. W. Mebs. 42 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 15 cents.

The relationship between stress and strain, and between stress and permanent set, for 18 : 8 alloy as affected by prior plastic deformation is discussed. Hysteresis and creep and their effects on the stress-strain and stress-set curves are also considered, as well as the influence of duration of the rest interval after cold work and the influence of plastic deformation on proof stresses, on the modulus of elasticity at zero stress (E_0), and on the curvature of the stress-strain line. A constant (C_1) is suggested to represent the variation of the modulus of elasticity with stress.

Curves of variation of proof stress with prior plastic deformation often have many oscillations between high and low values. Causes of the most abrupt of these oscillations are: Variation in the duration of the rest interval, and variation in the distribution of the experimental points throughout the range of extension. These oscillations probably are due in part to variations of internal stress. Variations in the rest interval generally have opposite effects on the slopes of the stress-set and the stress-strain curves. When E_0, C_1, and the corresponding stress-set curve are known, a fairly good picture is available of the elastic strength. Slight pre-stretching, to the extent of a small fraction of 1 percent, generally causes considerable improvement in elastic strength. Whether most of the improvement is permanent can be established only by further experiment.

Comparison is made between values of E_0 and C_1 for 18 : 8 alloys and for other typical metals and alloys.

Report No. 671, A Theoretical Study of the Moment on a Body in a Compressible Fluid, by Carl Kaplan. 18 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

The extension to a compressible fluid of Lagally's theorem on the moment on a body in an incompressible fluid and Poggi's method of treating the flow of compressible fluids are employed for the determination of the effect of compressibility on the moment on an arbitrary body. Only the case of the two-dimensional subsonic flow of an ideal compressible fluid is considered.

As examples of the application of the general theory, two well-known systems of profiles are treated; namely, the elliptic profile and the symmetrical Joukowski profiles with sharp trailing edges.

The effect of compressibility on the position of the center of pressure is also discussed. In order to determine this effect, it is necessary to calculate the additional circulation induced by the compressibility of the fluid for both the elliptic and the Joukowski profiles. For these two types of profile, the centers of pressure in the compressible and the incompressible fluids are found to coincide for a definite and fairly small angle of attack, which is essentially dependent on the thickness coefficients. For angles of attack less than this neutral angle, the center of pressure in the compressible fluid is farther from the nose and, for angles of attack greater than the neutral angle, nearer to the nose than the center of pressure in the incompressible fluid.

Several numerical examples of both the elliptic and the Joukowski profiles are given. The results show that, although the effect of compressibility on the moment and on the lift may be large, the effect on the center of pressure for conventional profiles is negligible.

THE RAMAN EFFECT AND ITS CHEMICAL APPLICATIONS, by James H. Hibben. 544 pages, illustrations, tables, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1939. Price $11.00.

Much has been written in the past ten years on this subject, since Sir V. C. Raman announced the results of his observations. In fact several publications have been mentioned in these columns both as to the physical and chemical applications of this effect. These many papers and books are good evidence of the work and interest created by this one more means through which the behavior of atoms in molecules may be measured independently of the state of aggregation. While the subject has what may be termed two sides, physical and chemical, both points of view reveal a fascinating encouragement to penetrate inward to fundamentals. This book is concerned with the many chemical applications of the Raman effect which are independent of the physical mechanisms responsible for the Raman lines. These serve to explain, to a certain extent, the common facts of chemistry.

In endeavoring to describe how the Raman spectra have contributed to the understanding of molecular constitution and molecular behavior the author apparently has given considerable thought on a logical arrangement of the material. The result is the presentation of the large mass of data in such a way as to emphasize the significant conclusions which can be drawn from it. When an individual substance might logically be treated in more than one place, it is located where it can be treated to greater effect and at other places cross references are inserted in the text. Generally, however, the progress is from the simple to the more complex.

The treatment is divided into three parts. The first is a general discussion of the Raman effect, its practice and theory. It opens with the topic of the origin and nature of the Raman effect which chapter is purely descriptive and gives the processes in a much over simplified manner. Then experimental methods and definitions of terms are given as a foundation for more detailed discussion which follows. The method of presentation in Part II and Part III emphasizes the applications of the Raman effect to constitutional problems. Part II is devoted to the Raman spectra of organic compounds and Part III of inorganic compounds. The theoretical relations of this effect to the vibrational and rotational spectra of simple as well as complicated molecules, when symmetry conditions permit are not neglected here, but are treated in much less detail than in Part I. This permits those who are interested in any of the multitudinous applications to organic and inorganic chemistry and to biochemistry to ascertain its uses and limitations independently of a detailed and exact presentation of the theory involved.

The many literature references and a list of publications concerning each chemical compound investigated are given in convenient form which can be

used to advantage for reference purposes. The book undoubtedly will be of assistance to those now working in this field and it should inspire many to use the Raman spectra in solving some of the problems which confront all scientific investigators.

R. H. OPPERMANN.

THE PSYCHOLOGY OF PHYSICS, by Blamey Stevens. 278 pages, illustrations, 15 × 23 cms. Manchester, Sherratt & Hughes. Price 7s. 6d.

The title of this book is such that it will raise curiosity in the mind of everyone who has studied physics, especially those with an inkling or some familiarity with some of the revelations of the "New Physics" in the hope that much of the real fundamentals of physics will be exposed by a treatment on the common ground of psychology and physics. As a matter of fact the book is intended as a contribution in this direction. It is stated that the book provides a course of rational psychology, applied to the study of physics, prepared for the use of elementary students

As would be expected, the first point of attack is in the teaching of physics and the author states in the preface that in spite of this almost mechanical procedure a few students develop a measure of success by means of intuition which is defined as the use of instinctive knowledge subconsciously. Exception can and will be taken here by many teachers, especially in the light of the numerous examinations and investigations of methods of presentation in the classroom. Furthermore it is stretching pretty far to say that a psychological point of view of the subject resulting from a method of teaching will necessarily advance our knowledge by reason of increased numbers of successful students. But this is only a passing remark on the contents of the book.

The construction of the book is one of first asking a question, then giving the reader an opportunity to answer it in his own mind before reading the answer in accordance with psychological principles. A contrast is thereby created, which is intended to create thought along the lines indicated and at the same time presenting the author's argument. The questions are very many in number covering a wide area and include relationships of space, time, inertia and such subjects as stress and strain, conservation, relativity, electric attraction and repulsion etc. Just how elementary a student should be to use the book in its entirety is a problem in view of this coverage.

To do justice in a review of the treatment here given would be beyond reasonable space limitations. Suffice to say that the author's concept is one of evolution. Laws of physics depend upon the psychological organizatlon that has evolved in man's ancestors by natural selection. Natural selection is in turn founded on the materials supplied by physics, such as the molecular and chemical reactions that take place within the organisms that are evolved. The whole circuit of cause and effect is thus completed. Just how far this can go is of course a problem, but certainly the view is radical and needs a great deal more than is here revealed to place it in a serious category.

R. H. OPPERMANN.

STEAM, AIR, AND GAS POWER, by William H. Severns and Howard E. Degler. Third Edition, 511 pages, illustrations, tables, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $4.00.

Heat power engineering is now having an unusual turnover in viewpoint. True, there has always existed in industry, considerable activity with regard to the many phases of this subject resulting in a gradual definite raising of efficiencies and better applications of heat power to do its particular job. But in recent years, due to economic conditions, a more concerted drive in the way of research, and an improvement in knowledge over the loose ends left from previous work, an almost new conception exists that engineers on the firing line must of necessity take heed.

This is the third edition of this well known book. In it are incorporated the latest proven methods and apparatus in the heat power plant. Those who are familiar with previous editions know of the style of presentation, for nothing has changed in this respect. Much of the subject matter, however, has been changed in the way of bringing it up-to-date. The general construction of the book is a logical progression beginning with a brief introduction and proceeding through chapters on thermodynamics, heat power plants, steam, fuels and combustion which has been rearranged and made more concise, steam generators and auxiliaries containing the more recent advances, feedwater treatment including equations for chemical reactions which is a feature of this edition, draft apparatus, engines, turbines, internal combustion engines etc.

The subject matter is presented in the form of a text with worked out examples as well as carefully selected problems for exercise. At the end of the book there are supplementary data in the form of tables which include an abridged form of Keenan and Keyes thermodynamic properties of steam, and a subject index. The book is essentially one for direct practical application of theory to practice. The methods used in presentation, the coverage, and the general arrangement of subject matter make it useful to the student and engineer alike.

R. H. OPPERMANN.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. Transactions, Volume 135. Iron and Steel Division, 1939. 590 pages, illustrations, 16 × 24 cms. New York, Institute. Price $5.00.

This is the twelfth of a series of volumes containing papers and discussions presented before the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers since 1928. It contains some 582 pages and there is an index in the back. The papers, numbering 20, include treatments on the reduction of iron ores under pressure by hydrogen, solidification of rimming steel ingots, structure of iron after drawing, swaging, and elongation in tension, chromium in structural steel, the fracture of steels at elevated temperatures after prolonged loading, and others. The Howe Memorial Lecture for 1939 entitled "Some Things We Don't Know about the Creep of Metals" by H. W. Gillett is printed in full. The book is made up in the good quality of previous years, the illustrations being of very high grade.

R. H. OPPERMANN.

THE GLASS GIANT OF PALOMAR, by David O. Woodbury. 368 pages, plates, illustrations, 16 × 25 cms. New York, Dodd, Mead & Company, 1939. Price $3.00.

There have been many books written in a popular vein on astronomy. That these have been widely read is evidenced by the trend of conversation often heard among various classes of laymen at appropriate times. Most of these books are of a kind devoted to the translation of the highly technical work of the astronomer into the every day language and understanding of the layman, together with a sprinkling of history from the time of the ancients, and an attempt at "sugar coating" the past achievements and hopefulness of future achievements. Undoubtedly this type of book has done much for the science in the way of bringing public appreciation, a thing so necessary in this world of today. There should be more of it in all the sciences.

The Glass Giant of Palomar is a book just a little removed from the above mentioned classification. It is written for the layman, it gives some ancient history which leads to modern conceptions, and it describes some of the practical accomplishments of astronomy. However, there is much more contained in the story. The author has not forgotten the human element, the characters of the workers, their economic conditions and difficulties, and their ingenuity in coping with economic and technical barriers to one of the most ambitious undertakings every attempted by science, which is the 200 inch teleschope at Palomar.

The story is written principally around the life of Dr. George Ellery Hale. As a character study it is remarkable. His work at Yerkes, Mt. Wilson and finally at Palomar is given in vivid detail. The revelation of the many sided necessary requirements to success is well done and the only conclusion that can be reached by the reader is a monument to Dr. Hale. As the story proceeds the lives of many others, specialists and non-specialists, are cleverly woven in. The difficulties of obtaining money, business transactions, transportation, floods and earthquakes, the selection and manufacture of the various materials for the glass giant, and the many intricate engineering problems are all covered. In all of this the manner of presentation makes the book fascinating with little realization, at the time of reading, of the amount of knowledge actually absorbed. After completing the book there remains an urge to reminisce and marvel at the enormousness of the work described. The book goes far toward educating the reader and the lessening of misunderstandings that might exist.

R. H. OPPERMANN.

HANDBOOK OF CHEMISTRY; compiled and edited by Norbert Adolph Lange, assisted by Gordon M. Forker. Third edition, 1792 pages, 14 × 20.5 cms. Sandusky, Handbook Publishers, Inc., 1939, price $6.00.

The second edition of Lange's Handbook has found a useful place in many laboratories, because of the wide range it covers and the convenient form in which the data are presented. The third edition is thus insured a ready welcome, and little need be added except to list the changes and additional material incorporated in the new edition.

The following is a list of tables not in the second edition and now offered for the first time:

Physical and Mechanical Properties of Cast Metals

Reduction of Barometer Readings to Sea Level
Symbols of Thermo- and Physico-Chemical Quantities
Dimensional Formulas
Properties of Various Photographic Film Emulsions
Comparative Photographic Emulsion Speed Ratings.

The following tables in the second edition have been extended or completely rewritten:

First-aid Measures for Accidents and Antidotes of Poisons
Changes in Atomic Weights from 1894 to 1939
Effective Radii of Atoms and Ions
International Table of the Radioactive Elements and their Constants
The Vitamins
Pipes, Valves and Fittings
Flow of Water and of Gas in Pipes
Immersion Refractometer Readings of Methyl Alcohol and Ethyl Alcohol
Surface Tension of Various Substances
Definitions of Chemical Terms
Factors for Interconverting Saybolt, Redwood and Engler Viscosimeter Readings.

GEORGE S. GARDNER.

A TEXT-BOOK OF QUANTITATIVE CHEMICAL ANALYSIS, by Alex. Charles Cumming and Sydney Alexander Kay. Seventh Edition, 496 pages, illustrations, 15 × 23 cms. New York, D. Van Nostrand Company, Inc., 1939. Price $5.00.

The first edition of this book was written in 1913 and succeeding editions up to the present one, the seventh, have indicated a keeping in step with the progress of the subject as well as the popularity and consequent demand for the book. For those who are not familiar with any of the previous editions it is pointed out that generally a method of simplicity and directness has been a characteristic of extreme value. This seventh edition is no exception.

The book is divided into seven parts, arranged to give the principles of quantitative analysis first and then proceeding to where a special study of chemistry is required. After devoting some thirty-four pages to general principles, volumetric analysis is introduced which proceeds through acidimetry and alkalimetry, oxidation and precipitation, and electrometric methods. Next, gravimetric analysis is taken up and in this section reference is made to the description of precipitation operations in the foregoing part while some of the apparatus and processes peculiar to this kind of analysis are described. For the determination of a very small quantity or the merest trace of a substance, the book describes colorimetric methods. Here stress is laid on the necessity that the solutions to be compared contain as far as possible the same quantities of admixed substances, that they are at the same temperature, that they are diluted to the same volume before adding the reagent, and that the order in which the reacting substances are mixed and the time allowed before comparison is made are as nearly the same as possible.

The following sections are more of a practical nature. Among the systematic analyses can be found determinations for gold, lithium, molybdenum, strontium, tungsten and vanadium. A very important section is that on gas analysis where

procedures are explained using the Hempel and Orsat apparatuses, and analyses involving the use of a Lunge nitrometer. The last part of the book gives attention to water analysis in which is covered the various chemical examinations with a concluding statement on the significance of the results of analysis of a drinking water. The appendix contains a considerable amount of helpful information such as a list of common reagents, preparation of pure gases, indicator solutions, etc.

The book is modern in its presentation and content. It is a worthy successor to the previous editions.

R. H. OPPERMANN.

PHYSICS, by Erich Hausmann and Edgar P. Slack. Second Edition, 756 pages, illustrations, 15 × 23 cms. New York, D. Van Nostrand Company, Inc. Price $4.00.

One of the things most sought for by workers in every field is a single tool that can be applied equally well in many applications. Its usefulness is enhanced by the ingeniousness of its design and the efficiency of its employment. When these are paramount, often it is found that this single tool has value for more purposes than those for which it was originally intended. Text books can be classed as tools of this nature. A well-constructed text is used to fit into a course of education, and as a reference work for those in active participation in the field. How widely these purposes are served depends upon the flexibility of the book—its ability to fit into various educational situations, and the effectiveness of its arrangement so that specific information can be obtained quickly.

Flexibility in courses of study is the stated feature of this book. It is intended for courses in which all parts of the subject are covered in one year, or for individual courses in mechanics, heat, electricity and magnetism, and sound and light that extend over longer periods. There are a number of advanced sections which may be omitted in the shorter courses. The book is in its second edition, the first having been published in 1935 with several reprints. The lines of revision have extended from rearranging the sequence of chapters to the merging of material into a single chapter. The method of presentation generally is that of discussion, instruction, and exercise. The latter includes over 800 problems and the earlier policy of giving at the end of the book the answers of only the odd numbered problems has been continued. While the 729 pages of text may at first glance be voluminous, a further examination will reveal that the subject matter is cleverly divided into parts reasonably short so that coverage would be facilitated.

The subject index in the back is quite well done. It adds considerably to the value of the book for reference purposes. Students as well as practicing engineers should find here a book that presents in a logical way the essentials of physics.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Rutherford, Being the Life and Letters of the Rt. Hon. Lord Rutherford, O. M., by A. S. Eve. 451 pages, plates, illustrations, 17 × 26 cms. New York, The Macmillan Company, 1939. Price $5.00.

Molecular Spectra and Molecular Structure. I. Diatomic Molecules, by Gerhard Herzberg. 592 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1939. Price $6.50.

The Photographic Process, by Julian Ellis Mach and Miles J. Martin. 586 pages, illustrations, 19 × 25 cms. New York, McGraw-Hill Book Company, Inc., 1939. Price $5.00.

The Pageant of Electricity, by Alfred P. Morgan. 363 pages, plates, illustrations, 15 × 23 cms. New York, D. Appleton-Century Company, 1939. Price $3.50.

Excursions in Science, edited by Neil B. Reynolds and Ellis L. Manning. 307 pages, 15 × 21 cms. New York, McGraw-Hill Book Company, Inc. Price $2.50.

Tides in the Affairs of Men, An Approach to the Appraisal of Economic Change, by Edgar Lawrence Smith. 178 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $2.00.

The History of Photography, Its Relation to Civilization and Practice, by Dr. Erich Stenger. 204 pages, plates, 16 × 24 cms. Easton, Mack Printing Company, 1939. Price $5.00.

The Philosophy of Physical Science, by Sir Arthur Eddington. 230 pages, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $2.50.

Elementary Theory of Equations, by William Vernon Lovett. 237 pages, illustrations, 16 × 24 cms. New York, Prentice-Hall, Inc., 1939. Price $2.50.

Automatic Design of Continuous Frames in Steel and Reinforced Concrete, by L. E. Grinter. 141 pages, illustrations, 15 × 24 cms. New York, The Macmillan Company, 1939. Price $3.00.

Transactions of the American Institute of Mining and Metallurgical Engineers. Volume 135. Iron and Steel Division, 1939. 590 pages, illustrations, 16 × 24 cms. New York, Institute. Price $5.00.

Canada, Dominion Bureau of Statistics, General Statistics Branch, Department of Trade and Commerce, The Canada Year Book, 1939. The Official Statistical Annual of the Resources, History, Institutions, and Social and Economic Conditions of the Dominion. 1190 pages, plates, illustrations, maps, 16 × 23 cms. Ottawa, King's Printer, 1939. Price $1.50.

Canada, Dominion Bureau of Statistics, Agricultural. Report on the Grain Trade of Canada for the crop year ended July 31, and to the close of Navigation, 1938. 227 pages, illustrations, 16 × 25 cms. Ottawa, King's Printer, 1939. Price 50 cents.

National Advisory Committee for Aeronautics. Technical Notes: No. 731, Tests in the Gust Tunnel of a Model of the XBM-1 Airplane, by Philip Donely and C. C. Shufflebarger. 13 pages, illustrations. No. 732, A Simple Method of Obtaining Span Load Distributions, by Albert Sherman. 23 pages, plates. No. 733, Experimental Study of Torsional Column Failure, by Alfred S. Niles. 59 pages, illustrations. No. 734, Pressure-Distribution Investigation of an N.A.C.A. 0009 Airfoil with a 50-Percent-Chord Plain Flap and Three Tabs, by William G. Street and Milton B. Ames, Jr. 42 pages, illustrations. 4 pamphlets, 20 × 26 cms. Washington, Committee, 1939.

CURRENT TOPICS.

West Virginia Building at Fair Shows Smallest Metal Tube.—What is believed to be the smallest metal tube in the world was placed on display at the West Virginia Building at the World's Fair recently, it was announced by Senator Dan B. Fleming, commissioner in charge of the State's exhibit at the Fair. Made of pure nickel, its total diameter measures 26/10,000 of an inch—the size of an average strand of human hair. The hold of the tube is 7/10,000 of an inch or less than one-third that of a piece of hair. Senator Fleming pointed out that the tube is so small that a coil one pound in weight strung in a straight line would reach from the Trylon, around the peak of the Empire State Building and down to the Battery—a distance of approximately 11 miles. The tube is displayed in a novel device known as the "Quadrylon," made of transparent material to a design suggested by the Trylon. Within the Quadrylon, the tube is submersed in oil. Air, forced through the tube, actually blows bubbles. The tube itself can barely be seen with the naked eye and magnifiers are provided for visitors. For purposes of comparison, a common pin is suspended by a strand of hair alongside the tube. Larger size nickel tubing, produced at the International Nickel Company plant at Huntington, West Virginia, was used for making this minute display which was drawn down to its present dimensions by the Superior Tube Company, Norristown, Pa. Produced especially for display purposes at the Fair, the tube as yet has no commercial applications though tubes of slightly larger size are used in certain types of hypodermic needles and for various laboratory purposes.

R. H. O.

Byrd Antarctic Expedition to be Housed in Buildings Using Teco System of Construction.—Bid invitations for eight prefabricated, demountable buildings of the Antarctic type, to house the base parties of the first expedition of the United States Antarctic Service, under the leadership of Rear Admiral Richard Evelyn Byrd, have been issued by the Washington Quartermaster's Depot of the War Department. These structures will use Teco 4" split ring connectors in the trusses which have a design load of 150 lbs. per sq. ft. of horizontal projection of roof area. These eight structures, consisting of two bunk houses, two workshops, two scientific

laboratories, and two outpost buildings, have been designed by Major Andre L. Violante, construction division, Quartermaster Corps, and call for the timber connector method of construction. This system has been selected because of its adaptability to transportation and ease of erection as well as to assure adequate support for unusually high snow and wind loads. All buildings are panelized, with panels for the roof, walls, floors and gables. These panels are made up with insulation in place, and cutouts are provided to give access for making bolt connections during erection. Panels are sheathed on the outside with tongue and groove siding, and on the interior with plywood. To save space, it is planned to store supplies, etc., against the exterior of the structures allowing them to become covered with ice and snow. In addition, this will offer partial protection against the exceedingly high wind velocity to which the buildings will be subjected.

R. H. O.

Aircraft Fire-Fighting Equipment.—(*Engineering*, Vol. 148, No. 3841.) Despite the appearance in recent years of many devices for making flying safer, the chief danger has been, and still is, that of fire. The British Air Ministry have now taken definite steps to combat the fire risk by ordering a type of automatic fire extinguisher as a standard fitting for R.A.F. aircraft. The new automatic equipment causes the immediate discharge, at suitable points in the machine, of a quantity of methyl bromide under pressure, if any of the following three conditions should arise; (1) in the event of a crash; (2) if the aeroplane turns upside down on landing; (3) if a fire breaks out in the air or on land. In addition to these fully automatic actions, the pilot is able to operate the extinguisher by pressing a switch if he considers a crash imminent, or if he detects some other defect in flight that might lead to a fire. The system is suitable both for single or multi-engined aircraft, and in the latter case, a crash or the overturning of the machine will operate all the extinguishers, while a local fire on any engine will be dealt with individually. All the switches initiate the extinguisher system in the same manner, i.e., they close an electrical circuit which brings about the discharge of liquid methyl bromide through a pipeline system, the liquid evaporating on coming into contact with the atmosphere. The evaporation of the liquid cools the hot metal surfaces with which it comes into contact, and the vapor effectively extinguishes any flames that exist. Another important feature is that the methyl bromide vapor does not corrode the metal surfaces on which it is sprayed, and tests have shown that no corrosion is

caused even by injecting the vapor into the induction system of the engine.

R. H. O.

The Effect of Low Temperatures on the Human Body.—L. KAY WRIGHT in *Refrigerating Engineering*, Vol. 38, No. 3, briefly reviews a number of elementary studies on this subject in an effort to make a contribution toward giving it a status in the therapeutic field. Doctors attending a recent meeting of the American Medical Association were shown a motion picture record of cancer patients placed in a deep sleep by refrigeration and held in that condition for five days. In intermittent doses, as many as forty days of this sleep have been given. This picture described the work of Doctors Fay and Smith of Philadelphia. Patients pronounced hopeless cancer cases are alive and out of pain today. Treatment by refrigeration consists of covering the nude patient with cracked ice and turning on electric fans to obtain even cooling. Thus, sleep is induced, similar to the drowsiness exhibited by a freezing person. Patients report no pain. In about three hours the body temperature is lowered to below 90° F. When it reaches a temperature of 89°, the ice is removed and the patient is kept in a cold room sleeping much as a bear hibernating in his cave. After the proper period he is awakened by hot applications and hot coffee, with no memory of what happened or fear of repeating the process. Heretofore doctors have always thought that any drop in human temperature below 90° was a positive sign of death—in these experiments such temperatures, and even lower ones, brought no unfavorable results. The growth of cancer cells was arrested, and pain was reduced or eliminated. Means of improving the method of application have been offered by enterprising refrigerating engineers in the shape of a refrigerated blanket. This device is a partner to a product already on the market, an air-conditioned blanket. The effect of cold on living organisms indicates an interesting field for further research.

R. H. O.

The Kleinschmidt Still.—ROBERT V. KLEINSCHMIDT, Arthur D. Little, Inc., Cambridge, Mass., before the American Chemical Society. This unit has been developed primarily for simple distillation and concentration of liquids which do not require fractionation. It consists of a mechanical vapor compressor, acting as a heat pump, in conjunction with carefully designed heat exchangers, continuously to recycle latent and sensible heat within a thermally isolated system. The thermodynamic advantages of such a system have been

well recognized for many years, but its practical application has only recently been successfully accomplished. The very high energy efficiency obtainable (50 to 80 watt hours of electric power per gallon of distilled water produced) is in many cases of secondary interest to other advantages, such as ability to handle sea water without serious scale formation, absolute sterility of condensate, and extreme simplicity of installation involving only power (15 H.P. for 100 gallons per hour), the supply of water to be distilled, and the distillate and concentrate lines. No steam piping and no condenser water are used. Although investment costs are higher than for ordinary steam heated stills, operating costs are so low as to offset this for continuous operations. Among the fields that have already received detailed study are: Recovery of fresh potable water from sea water, concentration of sweet water in sugar refineries, regeneration of hygroscopic salt solutions used in air conditioning and drying, and solvent recovery. This development represents one of the first important applications of the heat pump principles outside of the field of refrigeration.

R. H. O.

Commercial Utilization of Industrial Wastes.—H. E. HOWE and F. J. VAN ANTWERPEN, *Industrial and Engineering Chemistry*, Washington, D.C., at the recent meeting of the American Chemical Society in Boston, Mass., conducted a survey type discussion, the principal purpose of which was to recall the more important of the large number of instances where industrial or trade wastes have been converted through research into raw materials for the manufacture of commercial products. In this, differentiation must be made between by-products in the usual sense and materials which are true wastes—not only useless but often involving expense for their satisfactory disposition. Under such classification may be included the manufacture of sulfuric acid and recovery of elemental sulfur from smelter gases, the production of sulfuric acid from the hydrogen sulfide in petroleum still gases, and the recovery of by-product sulfur from the hydrogen sulfide in illuminating gas. Sulfite waste liquor has become the source of vanillin and a number of other products. Waste casein finds its way into resins and adhesives; the fermentation residues in the alcohol industry have been converted into cattle foods and the carbon dioxide into dry ice. Potash is recovered from the dusts of the cement industry and building blocks have been made from fly ash. In a sense the long list of solvents now recovered from gases derived from petroleum represent success in the use of otherwise waste materials. The

same may be said of cements made from blast furnace slag, and synthetic methanol utilizes carbon monoxide present as an interfering substance in gases used in the fixation of nitrogen. Furfural from oat hulls, celotex from bagasse, are other examples of this type of material.

R. H. O.

Flames and Furnaces.—An International Conference on Flames and Furnaces will be held from the 17th to 20th of September, 1940, at the Royal Institution in London. The Institute of Fuel has made itself responsible for convening the Conference, and the technical organization has been undertaken by the British Coal Utilization Research Association. The progress in the scientific study of flame by the methods of chemical kinetics and spectroscopy is opening up new fields which have great engineering and industrial possibilities. One purpose of the Conference is to bring these new developments to the notice of engineers and industrialists with a view to accelerating their practical application. Modern industry is calling for higher performance from furnaces and this creates problems which can sometimes only be solved by fundamental research. The Technical Programme of the International Conference in 1940 has been prepared by a Committee of thirty engineers and scientists under the chairmanship of Mr. J. G. Bennett, the Director of the B.C.U.R.A., and constitutes a planned attack on the problem of flames and their industrial applications. Flames in the internal combustion engine and explosive flames generally are excluded from the scope of the Conference, which will be concerned with the free combustion of gases, liquids and solids in air. This field is, as a matter of fact, almost entirely unexplored; and the Conference should, therefore, result in the collection and dissemination of hitherto uncorrelated information of much interest and practical value to the Gas, Oil and Coal industries.

R. H. O.

Hot Water Is By-Product of Top Burner Cooking.—S. H. KAHN. (*Gas Age*, Vol. 84, No. 5.) A Swiss engineer, Henri J. Wulser, has just patented a new system whereby he can heat water with the heat that generally goes to waste in a gas range. The system is particularly attractive from a number of standpoints. On the one hand it allows the housewife to heat the water for washing up her dishes while she is cooking the meal. In the second, it does not interfere with the normal use of the range, nor reduce its efficiency. Simply put, his idea is that in the ordinary gas range, too much heat

goes to waste around the top burners. To put this heat to some use, he replaces the cast iron bars by a specially designed system of copper tubes filled with water. These tubes form two rectangular frames, around the outside of the range top, one above the other. Connection between them is by tubes bent into a "V" shape, which can thus serve as pot rests at the same time. Each frame is connected to a coil, in a water tank, and the two coils are connected together at the top so that every time someone uses one of the burners of the range, the heat causes the water, which fills the whole system of frames and coils, to circulate. Since the coils are immersed in a tankful of water, as the water in the coils circulates and heats, it heats up the water in the tank.

R. H. O.

New Forest Service Bulletin Shows the Wide Range of Forest Products.—Forest products in such diverse forms as sausage casings and prefabricated houses, linoleum and phonograph records are the subject of a new illustrated bulletin on "Products of American Forests," by the Forest Service, U. S. Department of Agriculture. The bulletin is the work of J. ALFRED HALL, senior biochemist, and T. J. MOSLEY, senior technical reviewer, of the Forest Products Laboratory, Madison, Wisconsin. It declares that with a proper balance in land use in the United States, some 600 million acres of land now forested or suitable mainly for forests—at present partly in public and partly in private ownership—would be used primarily for the growing of trees, thereby keeping the land productive and habitable. The bulletin shows how the number of forest products in use has been increased by man's ingenuity and research from a few basic utilizations for fuel, shelter, posts, and implement handles to well over 4,500 listed, present-day uses, many of which, like cellophane and rayon in market form bear no apparent trace of wood or forest origin. The importance which forests might have in a world of diminishing mineral resources is suggested by the report that in certain European countries where shortage of materials has become a problem, scientists are now studying improvement of wood-burning stoves, and that wood is being converted through chemistry into human food, and gas or alcohol for motors. The basis for the food and alcohol is glucose—the same kind of sugar found in corn sirup. Glucose is obtained from cellulose by a process called hydrolysis. Cellulose is the principal constituent of the walls of the tiny wood cells. These are cemented together by another substance called lignin. The bulletin tells how wood ground to the fineness of wheat flour is

used in linoleum, dynamite, and plastic dials, knobs, phonograph records, and many other articles; how more than 60 individual chemical compounds have been isolated from vapors evolved in charcoal production, and how chemists look to the still mysterious lignin to provide many other valuable products, somewhat as coal tar has done.

R. H. O.

Wells Sees Crop Plants as Mines of the Future.—Mankind may be faced in a "measurably near future" with finding substitutes for coal and petroleum as sources of power. Investigation of the possibilities of farm-grown supplies of starch and cellulose as supplements to or substitutes for "irreplaceable natural resources" will be one of the long-term research efforts of the four regional laboratories of the Bureau of Agricultural Chemistry and Engineering now under construction. "To an extent not commonly realized," Dr. P. A. Wells, director of the eastern laboratory, said recently, "the broadening range of human wants has been supplied from irreplaceable natural resources—the mineral or fossil products of our mines and deep wells. So far as we can now foresee, civilization will never be free from its dependence upon some of these essential minerals. But the conviction is growing that to some large degree—how large it would be foolish to guess—many of our present requirements can be shifted to a less precarious basis. The most fundamental problem of all, mankind's rapidly growing utilization of heat energy, is an outstanding illustration. To all but a minor extent, civilization today rests upon the rapid utilization of fossil forms of solar energy—coal and petroleum. Use of the current supply of solar energy, stored as starch or cellulose by living vegetation, may become a vital matter in the measurably near future. Long before exhaustion of mineral reserves approaches, technological advances in the one field, or increasing difficulty and cost of extraction in the other, doubtless will lead to an increased dependence upon agricultural products for many other than their traditional uses."

R. H. O.